THE ACHROMATIC TELESCOPE,

AND ITS

VARIOUS MOUNTINGS,

ESPECIALLY

THE EQUATORIAL.

TO WHICH ARE ADDED

SOME HINTS ON PRIVATE OBSERVATORIES

BY

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PREFACE

PURCHASERS of Achromatic Telescopes, mounted equatorially or otherwise, having frequently requested me to furnish them with a concise statement of the leading principles upon which the construction and application of such instruments depend, it occurred to me that I should best consult the convenience of such applicants, by preparing for the press a brief summary of the subject This I have done, and the following pages are the result It must, however, be understood that these do not contain any discussion of principles, and if in my attempt at explanation of them I have exceeded the scheme I originally proposed to myself, it has been in those cases only in which the simplicity of the subject appeared to be favourable to my so doing At the same time, in the order I have adopted, my especial object has been so to direct the inquirer, that he may find little difficulty in determining precisely upon what points he requires more elaborate scientific information, and, for his further assistance, I have supplied him with such references as seemed to me to be needful

W S

London, July 1852.

THE

ACHROMATIC REFRACTING TELESCOPE.

Refraction and its effects

REFRACTION is that bending which a ray of light suffers when it passes obliquely from a rarer into a denser medium, or the reverse This effect is seen if a straight stick be plunged obliquely into water, the part immersed having the appearance of being bent upwards

It is also shown by the well-known experiment of placing an object, such as a coin, at the bottom of an empty basin, and withdrawing the eye till the coin is concealed by its edge, when, if water be poured into the vessel, the coin will reappear

Similar to the above is the effect produced by the atmosphere upon rays, which, proceeding from the heavenly bodies, traverse it on their passage towards the earth It is well known that the atmosphere diminishes in density as its distance from the earth's surface increases, and to a spectator at this surface the apparent altitude of a heavenly body will, therefore, be greater than its true altitude In the horizon the difference between the two exceeds the apparent diameter of the sun, so that, as in the case of the coin above-mentioned, an object may appear above the horizon when it is really below it

Lens

A lens is a piece of glass, or other transparent medium,

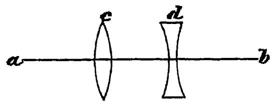
formed with a spherical surface or surfaces, and acts by its refracting power It is either convex or concave

If one side of a lens be flat it is *plano*-convex or concave

If both sides be either convex or concave, and the radii of curvature be equal to one another, the lens is said to be *double* convex or concave If the curves of a lens be of unequal radii, it is said to be *crossed*

If one side be convex and the other concave, it forms either a meniscus or a concavo-convex lens, the former having the effect of a convex, and the latter of a concave lens

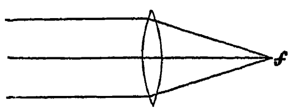
Fig 1



The axis of a lens is the line which joins the centres of the spheres of which its surfaces are sections, and it is evident that around this line the lens is in every respect symmetrically disposed Thus *a b* is the axis of the lenses *c* and *d*

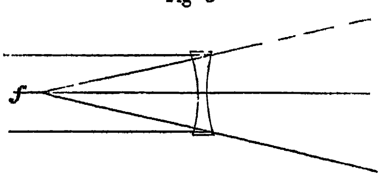
Parallel rays entering a convex lens are converged towards the axis and meet in a point *f*, called the focus The distance of *f* from the nearest surface of the lens is called the focal distance

Fig 2



Parallel rays entering a concave lens diverge from the axis The focus *f* is the point in which the diverging lines would meet if produced backwards through the lens to the axis In this case the focal distance is said to be negative

Fig 3



The focal distance in the case of a plano-convex lens is equal to the diameter of the sphere of which the lens is a section

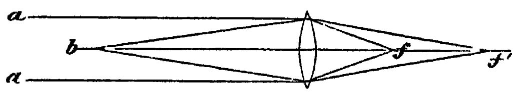
The focal distance in a double convex lens is equal to the radius of the sphere of which its surfaces are sections

The focal distance in the case of a crossed lens is found by dividing twice the product of the radii by their sum

The same rules apply to the determination of the foci of concave lenses, and for all lenses made of plate glass the results will be very nearly correct, but the several kinds of glass, and other substances, of which lenses can be formed, having different degrees of refracting power, the focal distance, which depends upon this refracting power, will, to some extent, vary accordingly

The focus for parallel rays is termed the principal or solar focus, and is the point upon which the rays from a celestial object are condensed, thus, the parallel rays *a a* will be converged to *f*, the principal focus of the lens, but if the radiant

Fig 4

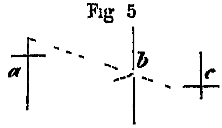


point be nearer to the lens, as at *b*, then the focus will be removed to *f'*, and these two points, *b* and *f'*, are termed conjugate foci, and are in all cases convertible thus, if *f'* become the radiant point, *b* will be changed into the focus

Formation of images

If rays from an object *a* (fig 5) pass through a small hole in a window-shutter *b*, an inverted image of that object will be formed, either upon the opposite wall, or upon a piece of white paper or screen, placed at any distance, as at *c* Now, if the hole be enlarged, and a convex lens, the focal length of which is equal to *b, c*, be fixed in the window-shutter, the size of the image will remain unaltered, but the brilliancy and distinctness will be increased by the greater quantity of light received by the lens and condensed upon the screen at *c*

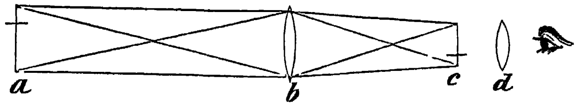
Fig 5



Let *c* (fig 6) be an image of the object *a* formed by the lens *b* upon a semitransparent screen Now, if this image be viewed by a lens *d*, of shorter focal length than that of *b*, the combination becomes a telescope, of which *b* is the ob-

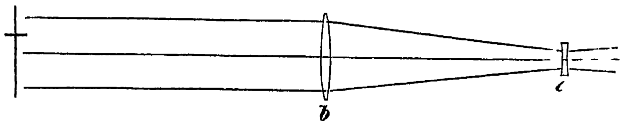
ject-glass and *d* the eye-glass The image in this telescope will be seen inverted

Fig 6



The telescope invented by Galileo consisted of a convex object-glass *b* (fig 7), and a concave eye-glass *c* placed within

Fig 7



the focus of *b* Objects are by this telescope shown erect, but the field of view is small, being limited by the aperture of the pupil of the eye This combination of lenses is now known, and almost exclusively used, as an opera-glass

Spherical and chromatic aberration

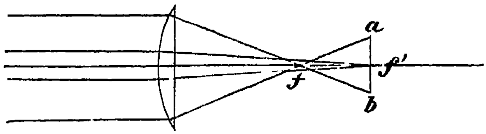
If the rays proceeding from an object, and passing through a convex lens, were all converged to points situated in the same plane, the task of making a perfect telescope would be a very easy one indeed, but this is by no means the case The optician has two difficulties to overcome, one arising from the form of the lens, and the other from the unequal refrangibility of the several coloured rays of which light consists—the former produces what is called spherical, and the latter chromatic aberration

Spherical aberration

We in the first instance spoke of the focus of a lens as a point Strictly speaking, however, those rays only which are refracted at the same distance from the centre of the lens, intersect one another in one and the same point, which is therefore the focus of only a single ring, and the foci of different rings are separated by small distances along the axis Thus, the rays which pass through a ring of the lens, which is situated near to the axis, have a focus more distant from the lens, than those which pass through a ring near to

the circumference, as is shown by fig 8, where f and f' represent the foci of marginal and of nearly central rays The

Fig 8



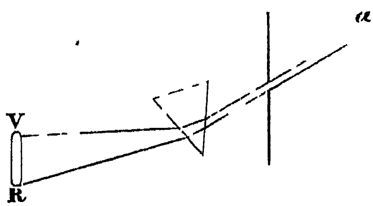
distance from f to f' is called the longitudinal spherical aberration The lateral aberration comprehends a circle, of which a, b is the diameter

The cure of spherical aberration is effected by giving suitable forms to lenses, and arranging them according to methods which are largely discussed in all works on optics The removal of chromatic aberration, or the production of the achromatic object-glass, is the effect of an expedient of so much beauty and ingenuity, and at the same time so comprehensible by the moderately scientific reader, that it shall be further treated of in this place

Dispersion by a prism

When a beam of light (a, fig 9) passes through a small circular hole in a window-shutter, and is refracted by a prism, it will be dispersed, and if a screen be interposed for the purpose of receiving the dispersed rays, a spectrum V, R will be formed upon it

Fig 9



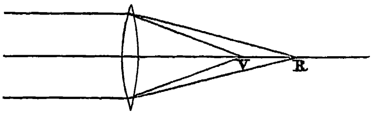
Although the light on entering the prism was perfectly white, it will now be separated into rays of various colours, which will be arranged in the order of their refrangibility Red, being the least refrangible, will be seen at R, and violet, the most refrangible, at V, the intermediate colours being orange, yellow, green, and blue

By a lens

Now, as in every case of simple refraction there is the same development of colour, it follows, that when rays from any object pass through and are refracted by a lens, there will be

a series of coloured images, extending from V to R (fig 10), V, R representing the amount of longitudinal chromatic aberration, and the general effect will be, that no distinct image is formed, or can be formed, by a lens under such circumstances

Fig 10



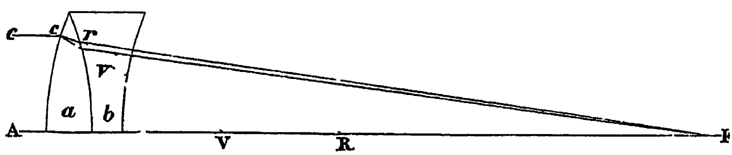
Reunion of the colours, or achromatism

Early experimentalists were led to the conclusion, that prisms of all kinds of glass, producing the same amount of mean refraction, form spectra of the same length from V to R (fig 9), or, in other words, have the same dispersive power, and hence, that achromatism, or the destruction of colour, could only be effected by equal and opposite refractions Now, as in such case, the reunited beam would emerge parallel to its first direction, they were led to believe that a refracting telescope, which requires the convergence of the rays in order to form an image of the object, could not be made achromatic This conclusion was found to be erroneous, for flint and crown-glass produce spectra of the same length, under a different amount of mean refraction, and these substances are therefore made use of for forming the achromatic object-glass

Achromatic object-glass

Let a (fig 11) be the section of half a convex lens of crown-glass, and b of a concave lens of flint glass, A F their common

Fig 11



axis If $c\,c$, a ray from any remote object, fall upon the external surface of the crown-glass a, the red, or least refrangible ray, will take the direction $c\,r$, and the violet, the direction $c\,v$, and if these rays were not intercepted, they would proceed to the axis, and form coloured images, as before shown (fig 10) The concave lens, however, now causes a divergence

of the rays to take place, and the ray *v*, being, as before, on account of its greater refrangibility, more bent than the ray *r*, they gradually approach each other and are reunited at F the focus, where a nearly colourless image will be formed

It is stated above that the image will be *nearly colourless* It will not be perfectly so, because no two media having different dispersive powers have yet been discovered, by which are formed spectra, wherein the several colours have an exact proportionality the one to the other, and consequently, no art of the optician can perfectly re-unite, by the second refraction, the colours which have been separated by the first This effect, known under the name of irrationality, is sometimes so great, that the formation of a tolerably achromatic object-glass out of two given discs of crown and flint-glass is an absolute impossibility A cure for this defect has been attempted by introducing a third lens of plate glass, and sometimes with good effect

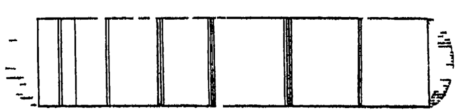
Irrationality

The terms *under-corrected* and *over-corrected*, as applied to an object-glass, may here be explained By referring to fig 11, it will be seen, that the purpose of the concave, or correcting lens of flint-glass *b*, is to effect the reunion of the rays V and R If it fall short of this object, the glass is in an under-corrected state, but if it do more than is required of it, the violet ray will have a focus beyond the red, and the order of the colours will be inverted This would be a case of over-correction

Fraunhofer's lines

In former times, much uncertainty attended all experiments on the solar spectrum with a view to the correction of colour, in consequence of the difficulty of defining the limits of each colour They are so softened off and blended one with another, that it is impossible to determine, with any degree of

Fig 12



certainty, where one ends and another begins. A discovery

of modern times, however, has removed this difficulty. The spectrum is crossed by dark lines, visible through a telescope, which divide its length into definite spaces (fig. 12). These lines are distinguished by a few of the letters of the alphabet, as A, B, C, &c., and it is now usual, when anything like precision is aimed at, to express the dispersive powers of media by the lengths of the spaces included between the lines A and B, B and C, and so of the rest.

Having now taken a brief view of the principles upon which the construction of the achromatic telescope is founded, the attention of the reader may be directed to their practical application.

A telescope, as before stated, is a combination of lenses connected by a tube or tubes.

The tube or tubes in which the lenses are set is called, technically, the *Body* of the telescope. The end of the tube to which the object-glass is fixed, is the *object-end*, and its opposite the *eye-end*. The rings in which the lenses are fastened are termed *cells*.

That in which the object-glass is fixed is the *object-cell*. The eye-glass, or glasses, together with the tube containing them, form the *eye-piece*.

Aerial telescope.

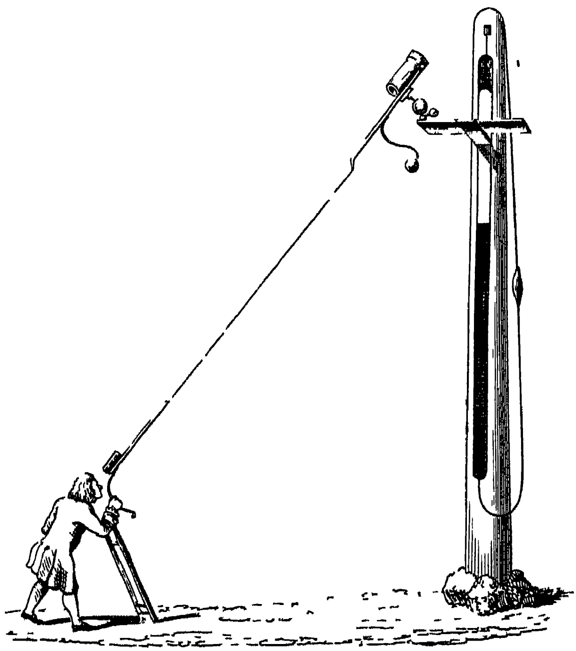
The object and eye-ends of many of the early telescopes, some of which were of great length, had no connecting tube whatever. The object-glass was placed upon a pole, and the eye-piece held in the hand, or fixed upon a rest or stand, at a distance from the object-glass equal to its focal length, which in one made by Huygens for the Royal Society was 123 feet.

Fig. 13 represents an instrument of this kind, which was termed the Aerial Telescope.

In order to direct such a telescope to a star or planet, the observer, in a dark night, had first to find the object-glass, which he did by the aid of a lantern. He next changed his own position till the object-glass intercepted the view of the object to be observed. Then this object-glass, being fitted with a ball and socket motion, was by means of a string or

wire, extending to the observer's hand, turned about till it appeared filled with a diffused light—an appearance which indicated that the axis of the lens passed through the object and the eye of the observer Now, without loss of time, the eye-piece had to be directed towards the object-glass, and, if all were dexterously managed, the observer would be gratified with a passing view of the object, only a momentary one, however, unless, by great and admirable tact, the object-glass and eye-piece were moved simultaneously, so as to keep the

Fig 13



object within the field of view It will be obvious that such a telescope must have been so difficult to manage, that, to one accustomed to the convenient arrangements of modern instruments, it is incomprehensible how any use whatever could have been made of it

The body, in telescopes of the larger class, is usually of

one tube, or if of two, they are firmly united by a strong screw-joint. In those of a smaller class, it is formed of several tubes sliding within each other, for the sake of portability. The latter form is applicable only to pocket telescopes used for terrestrial purposes, in which small deviations from straightness will not sensibly impair the performance of the instrument; but such a construction is wholly inapplicable to more powerful telescopes, for which the tubes cannot be too rigid, flexure deranging the concentric positions of the included lenses, and therefore injuring the effect.

Several rings, or *stops*, are placed within the body of a telescope. They serve the two-fold purpose of strengthening the tube, and of cutting off all extraneous light, which, if admitted, would diffuse a foggy or nebulous appearance over the whole field of view, and interfere greatly with distinctness. These stops have holes of such diameters, and are arranged at such distances, that the light is limited to the cone of rays converged by the object-glass. Care, however, must be taken, that the effective aperture of the object-glass is not lessened by them, or the advantages of the larger instrument will be lost. This may be proved by looking through from the eye-end of the telescope without an eye-piece, the eye being in or near the focus of the object-glass; under which circumstances the whole of the object-glass should be seen, but all parts of the intervening tube should be concealed.

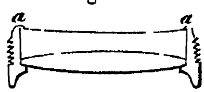
The stops, and also the inside of the tube, as far as practicable, at all events near the object-end, should be covered with a dull black pigment, in order that no light may be reflected in any direction within the tube. The paint may be a compound either of an alcoholic varnish and lamp-black; or of gold size, spirit of turpentine, and lamp-black. In the former case a sufficient degree of heat must be applied to drive off the alcohol by rapid evaporation; and in the latter the paint must be laid on cold, and remain a few days before the work will be dry enough to handle. The effect is the same whichever of these methods be adopted.

The performance of a telescope depends, in no small degree, on the accuracy of every part of the work, the tubes should be straight, and the joints and cells very carefully turned and fitted, for, if these precautions be not used, the lenses will not have a common axis, a condition indispensable to anything like a satisfactory effect

The fitting and fixing of an object-glass within its cell is an operation which requires a great deal of experience The lenses must not be so loosely held as to be at liberty to change their positions, neither must they be so tightly fixed as to incur the smallest risk of being bent or pinched, either by the screwing of the object-cell into the object-end of the tube, by contraction of the cell in cold weather, or by any other cause

Ordinarily, the object-glass is fixed in the cell by turning over the edge *a* (fig 14), with a tool of hard polished steel, and this plan answers very well for pocket-telescopes, which are used for terrestrial purposes only, and, for the most part, in clear and dry weather

Fig 14

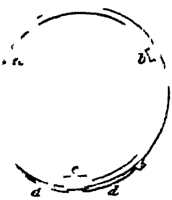


But, for an instrument that is likely to be exposed to a humid atmosphere, or to the copious dews of some of the finest nights for astronomical observations, this plan of fixing is objectionable, as it effectually precludes the possibility of wiping the interior surfaces of the lenses, however greatly they may require it.

A second method is to have a ring screwed into the back of the cell (*a*, fig 14), and pressing very gently against the glass In this case, a pin is soldered within the cell in the direction of its depth, and a notch being cut in the edge of each lens, it slides upon the pin, and is thereby guided and retained in its proper position

The effect of contraction of the cell, in cold weather for example, is a circumstance which requires a special provision in telescopes of large aperture, for if the cell were made so large, that it could not pinch the glass in extreme cold, it would be improperly loose at the temperature of our warmest

Fig 15

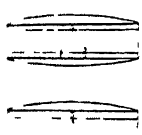


seasons The plan usually adopted is to have three points of bearing within the cell *a*, *b*, *c* (fig 15), *a* and *b* being projecting parts of the cell itself, and *c* a moveable piece, pressed into contact by the springs *d*, *d*, of which the strength is regulated so that their united action will support the weight of the object-glass.

It is necessary to warn the inexperienced observer, who may find himself under the necessity of removing his object-glass from the cell for the purpose of cleaning, that care must be taken to replace the lenses in all respects as they were left by the optician The same sides of the lenses must be in contact with each other, and the same face turned towards the object —an error in either of these respects will totally spoil the performance of the object-glass Many mistakes of this kind have occurred in the course of the author's experience, and have proved vexatious and expensive to those by whom they have been committed One of the most remarkable was the returning of a large and powerful telescope from a distant part of the world, with an elaborate paper on the defects of its performance, which were all removed by restoring the lenses to their proper positions within the cell

When an object-glass is set in a cell from which it can be removed, it is customary to put marks upon the edges of the lenses, as shown by fig 16, by which, whether the object-glass consist of two or three lenses, the faces which must be in contact are clearly pointed out Furthermore, it may be noted that in a double object-glass, *i. e* one consisting of two lenses, the convex must be the anterior, or that which is turned towards the object, and, in an object-glass consisting of three lenses, the surface which is ground to the shorter radius is generally the anterior face

Fig 16



Except in cases of necessity however, an object-glass should

never be removed from its cell. The only reasonable excuse for doing so, is, as before intimated, the removal of moisture which may have accidentally penetrated between the glasses, and when this has really occurred, inasmuch as its effect will be to produce a permanent stain, and in some degree to impair the brilliancy of the instrument, the sooner it is wiped off the better

The heavy flint-glass, which has a large quantity of lead in its composition, is peculiarly susceptible in this respect, so much so in some specimens, that exposure for a short time to a moist atmosphere, more especially if it be charged with any appreciable quantity of sulphuretted hydrogen, produces rapid decomposition of the polished surface.

A soft silk handkerchief, or a carefully chosen piece of chamois leather, may, perhaps, be most safely used for wiping the surfaces of an object-glass, and the application of a few drops of alcohol will assist in removing any impurities that adhere to the surfaces of the lenses When nothing but loose particles of dust require to be removed, a soft camel's hair brush is by far the best instrument for the purpose. Necessary, however, as an observer may find it, in the event of an accident, to meddle with his object-glass, it is much better, if possible, to avoid the occasion altogether, and to this end the utmost care should be taken to keep it out of the reach of dust or moisture

A telescope used at night in the open air should be furnished with a dew-cap, which is a cylinder of metal, black within, bright without, and made to fit upon the object-end of the telescope—its length varying from 8 to 18 inches, according to the aperture of the glass This, under ordinary circumstances, will prove a sufficient defence

In damp weather it is advisable to remove the object-glass from the instrument, even if it be under cover of an observatory This recommendation, as will be obvious, applies only to the object-glasses of equatorially mounted telescopes, and not to those of meridian instruments, for in the latter case the removal of an object-glass would disturb the adjustments,

and involve the astronomer in a good deal of trouble and annoyance, whereas, in the former, the removal and replacing of the object-glass can introduce no error of the smallest consequence. When an object-glass is out of use, it may be safely kept in a closely fitting metal case

As before mentioned, the heavy flint-glass, of which many of the finest telescopes are made, is the most liable to contract stains, and to such a degree in some instances, that the utmost care and vigilance are necessary in order to prevent it Dr Faraday has suggested the mixing of litharge with the black pigment with which the interior of a telescope-tube is usually covered, the effect of which would be to protect the flint-glass against the attacks of sulphuretted hydrogen, the great enemy in an atmosphere like that of London

Thus much concerning the preservation of an object-glass A few hints will now be given as a guide to the testing of its quality, and correcting its adjustment when needful.

The considerations especially to be attended to, are, the purity of the material, and the correction of the two kinds of aberration—the spherical and the chromatic It will, of course, be obvious, that, in addition to these matters, good workmanship in the formation of the curves, and judicious mounting and adjustment within the cell, are conditions indispensable to fine performance, for, even with good materials, and due attention to theory, it is impossible to produce a good object-glass without a competent degree of practical skill in working and mounting the lenses of which it is composed

Some judgement as to the purity of the glass may be formed in the following manner —

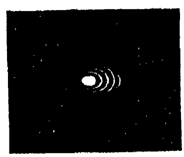
Direct the telescope to the moon's limb, or to the planet Jupiter [In the absence of these objects, a watch-dial fixed up at a distance of forty or fifty yards will, to a certain extent, answer the purpose] Take out the eye-piece, and place the eye in or near the focus of the object-glass Then, if the eye be moved about so that the patch of light, with which the object-glass appears partly filled, be made to pass and

repass slowly across its surface, any irregular refractions, and especially the presence of veins, will be immediately detected

With regard to the spherical and chromatic aberrations, the extent to which the first has been eliminated will be shown by the permanence of the focus, whether the image be formed by the centre or by the circumference of the object glass, and the last, by the absence of the more brilliant colours of the spectrum, for, as before stated, a perfect reunion of all the colours is in general unattainable

For the adjustment of an object-glass, an artificial star, formed by the sun's image reflected from a polished hemisphere of dark-coloured glass, or the ball of a broken thermometer tube, placed at any convenient distance, say from thirty to sixty yards, is an excellent object, so likewise is a small circular white disc upon a black ground The image should appear sharp and well-defined, and if, on being put a little out of focus, the enlarged disc does not expand equally all round, but presents an elongated figure in one direction, such as fig 17, the defect is generally attributable to the mounting—not to the glass—and arises from the object-end being tilted upon the tube This defect may be corrected in the following manner

Fig 17



Release the screws by which the object-end is fastened to the tube, and with a small wooden mallet give it a few gentle blows, either inwards towards the eye-piece, on that side where the elongation appears, or outwards on the opposite side [This direction supposes an inverting eye-piece to have been made use of] In this way the position of the object-end may be rectified, and the operation must be repeated till the enlarged disc opens concentrically, or till the curves (fig 17) become rings of light, and are equally distributed around the central nucleus When this has been effected, the screws may be again tightened

The tightening of the screws should be done gradually,

passing round the object-end three or four times, and not driving home one screw while the others remain loose If this caution be not attended to, the position of the object-end may be again deranged, and the operation require to be repeated

The judicious reader, keeping in view the above explanations, will hardly find himself at a loss to determine, and correct any ordinary defect or derangement to which a good object-glass is subject

The eye-piece of the telescope

The performance of a telescope depends more upon the eye-piece than is ordinarily imagined A bad eye-piece will undo the work of a good object-glass, and, consequently, too much care cannot be used in making the selection

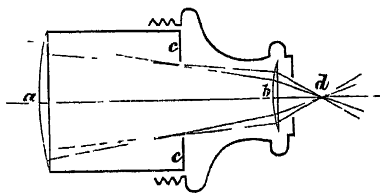
The loss of light by reflexion and absorption in an eye-piece consisting of two or more lenses, has induced some observers to give the preference to a single lens, either convex or concave—and, if such a lens be made achromatic, one very serious objection to its use is to a great extent removed There will remain, however, the inconvenience of having so small a field of view, that the working of a telescope with such an eye-glass, especially if it have any high degree of magnifying power, must be troublesome and embarrassing in the extreme

Four or five lenses, varying in focal length from about one-tenth of an inch to an inch, are sometimes mounted in a revolving disc, for use as eye-glasses This arrangement is convenient in so far as it enables an observer to change the magnifying power, without the trouble and loss of time attending the unscrewing and screwing of eye-pieces, but glasses so mounted are much less likely to have their axes coincident with the axis of the object-glass than those mounted, each one in an accurately turned cell The practice therefore is not recommended

The eye-piece most in use, and altogether the best adapted for astronomical purposes, is the Huygenian or *negative* eye-piece. It is represented in section by fig 18, *a* being the

field-glass and b the eye-glass They are generally of the plano-convex form, the convex surfaces being turned towards

Fig 18



the object-glass. The ratio of the focal length of the lenses is usually as 3 to 1—1 representing the eye-glass, but this admits of some variation It is, however, indispensable to achromatism that the distance between the lenses be equal to half the sum of their focal lengths

The stop c, c, by which the field of view is limited, is fixed in the focus of the eye-glass b, and the eye-hole d is of such magnitude, and at such a distance from the eye-glass, that the emergent pencils may just find a passage through it This hole serves as a guide to the eye, both as regards its place in the axis of the telescope and distance from the eye-glass The passage of rays proceeding from an achromatic object-glass is shown in the figure, where it will be seen, that, after refraction by the field-glass, they come to a focus at c, at which place an image of the object is formed The rays again open, and by passing through the eye-glass b are converged towards the point d, where they enter the eye, and form an image upon the retina, which is seen inverted

The rule for finding the focal length of a lens equivalent to an eye-piece of this description is this Divide twice the product of the focal lengths of the lenses which compose it by their sum, thus, if the focal lengths of the field- and eye-glass be 3 and 1, that of the equivalent lens is equal to

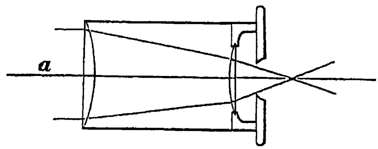
$$\frac{2\times 3\times 1}{4}=1\tfrac{1}{2}$$

It is usual to fit upon each eye-piece a dark glass cap

These caps form a series of shades, and apply, as occasion may require, to the eye-pieces indiscriminately

The positive or Ramsden's eye piece (fig 19), has its focus beyond the field-glass at *a*, and is therefore adapted for use

Fig 19



with micrometers and other instruments which have fixed wires or spider's threads in the focus of the object-glass, a case to which the negative eye-piece, in consequence of its having the focus between the glasses, is not suited The lenses are plano-convex, the convex sides being turned towards each other, the focal lengths of the lenses are equal to one another, and the field-glass should be so far within the focus of the eye-glass, that particles of dust upon the former cannot be seen when looking through the latter

The lens equivalent to an eye-piece of this description, is found by dividing the product of the focal lengths of the lenses composing it, by their sum less the distance between the lenses hence, if the focal length of each lens be 1 5 inch, and the distance between them 1 inch, it will be $\frac{1\ 5 \times 1\ 5}{3-1} = \frac{2\ 25}{2} = 1\ 125 = 1\frac{1}{8}$ nearly

The direction given to the rays in their passage through this eye-piece is shown by the figure, by which it will be seen that in this case, as in the previous one, the image is seen inverted

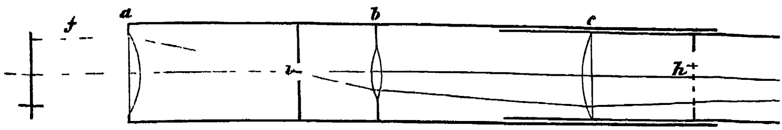
The erection of the image, however, is effected by the eye-piece next described, and which, on account of this property, is called the terrestrial eye-piece.

Fig 20 represents in section this eye-piece as it is now constructed

It contains four lenses, *a*, *b*, *c*, and *d*, *c* and *d* form a negative eye-piece, which can be unscrewed from the terrestrial

tube and employed separately for astronomical purposes indeed its power as an eye-piece is usually so arranged that

Fig 20



forms the lowest of the series fitted to a telescope, and is wel adapted for the observation of comets and nebulæ, or for th exploring of the heavens, a service to which the higher power are unsuitable

The course of the ray *f*, *g*, traced through the several lense will show the process by which the inverted image forme at *f*, by the object-glass, becomes erect at *h* in the focus o the eye-glass, where a stop is placed to define the field o view There is also a stop at *i* where the rays cross, the smal hole in which requires a careful adjustment, for if this b not attended to, either the effective aperture of the object glass may be diminished, or extraneous light will be suffere to pass through, and interfere with the distinctness of th image

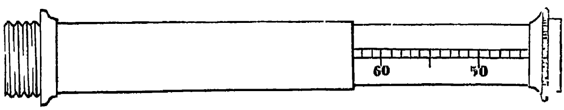
The magnifying power of this combination of lenses ca be increased by increasing the interval between *b* and *c*, an this is effected in the following manner A tube of suitabl length and diameter has an interior tube of nearly equa length sliding freely within it The lenses *a* and *b* are fixe at one end of the exterior tube, and *c* and *d* at the opposit end of the interior one, and by this means the distance *b* can be increased or diminished at pleasure, and the magni fying power varied accordingly

The reason of the increase of power by the increase of th distance *b c*, is simply this —Any ray in its passage from falling upon the margin of the field-glass *c*, will be mor nearly parallel to the axis as the distance *b c* is increased whilst the direction of the ray in passing from *c* towards

will remain constant, or very nearly so Now the magnifying power depending partly upon the relative direction of these two parts of the ray, any alteration in that of one of them, that of the other not being altered proportionately, will produce the effect mentioned

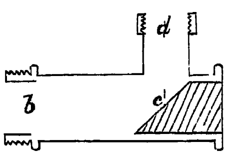
The external appearance of this eye-piece is seen at fig 21,

Fig 21



the graduated scale upon the interior tube shows the variation of power due to any amount of separation of the lenses in the figure the power indicated is 63

Fig 22



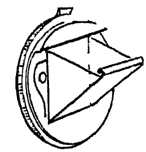
The diagonal Adapter (fig 22) is a contrivance for facilitating observation near the zenith

It consists of two tubes, *b* and *d*, soldered together with a rectangular elbow A plane reflector is so placed at *c*, where the axes of the tubes meet, that a ray entering by the axis of one tube is reflected centrally through the other, consequently an object in the zenith will be seen by an observer looking horizontally through the eye-piece. The screw on the outside at *b* fits into that of the focus tube, and that in the inside at *d* receives the eye-pieces The diagonal eye-piece differs from the adapter only in having a field-glass at *b* and an eye-glass at *d*, it is a positive eye-piece, and is used for micrometers and other instruments of that class For an ordinary telescope, however, the adapter is better than the eye-piece, inasmuch as it admits of all the powers being used with it

Fig. 23 represents a form of diagonal prism especially adapted for micrometers. Its principal advantage is that it may be used with all the positive eye-pieces of the instrument, but it is objectionable on one account, namely, that it

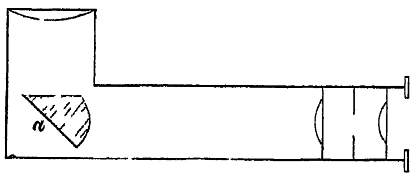
removes the eye to too great a distance from the eye-glass, and consequently, with high powers, very much diminishes the field of view Upon the whole, however, this is found to be the most convenient form of diagonal for its purpose, and is therefore in most general use

Fig 23



For some instruments, which, from peculiarity of construction, do not admit of the eye being placed near enough to use either the direct, or the short diagonal eye-piece, it is necessary to arrange the terrestrial eye-piece for diagonal observations Fig 24 shows the method adopted in such cases,

Fig 24



in which the glass prism at *a* serves the double purpose of reflector and lens

Magnifying power of Telescopes

The magnifying power of a telescope is found by dividing the focal length of the object-glass by that of the eye-glass, and, should the reader wish to obtain it in any particular case, he will now experience no difficulty, the rules for finding an equivalent lens, both for the Huygenian and Ramsden's eye-piece, having already been given But in cases in which great accuracy is required, the following more simple and practical method is now universally adopted

Let the telescope be directed to any distant object by daylight, and accurately adjusted to focus If the observer then withdraw his eye to about the distance at which he sees objects distinctly, he will perceive a speck of light in the very centre of the eye-piece This speck of light is an image of the object-glass, and the ratio of the diameter of the object-glass to that of its image represents the magnifying power If, therefore, the former be divided by the latter, the quotient

will be the quantity sought Thus, let the object-glass have a clear aperture of 4 inches, and the image above described measure $2\frac{1}{2}$ divisions upon a scale of hundredths of inches, *i. e* 025 of an inch Then $\frac{4}{025}=\frac{4000}{25}=160$ is the power sought

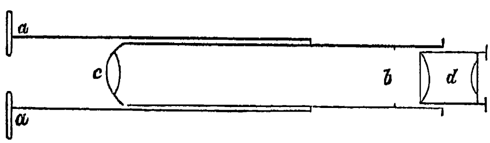
I may again remark that each eye piece must be adjusted to focus before the measure is taken, otherwise the conclusion will be erroneous, and this adjustment for a telescope used astronomically, should be to the principal focus of the object-glass, and ought, therefore, to be performed by means of a star or planet If this be done at night, and marks made upon the tube indicating the place of focus for each eye-piece respectively, the tube can afterwards be reset by these marks, and the images measured by daylight

Dynameter

The Dynameter, of which two kinds will be briefly described, is the instrument employed in measuring the image of the object-glass upon the eye-glass

Fig 25 represents in section the more simple instrument

Fig 25



of the two It consists of a compound microscope, the body of which slides within an external tube *a*, *a* At *b* a disc of parallel glass, or a slip of mother-of-pearl is fixed, upon which is a scale of equal parts, generally of 200 divisions to the inch, each fifth and tenth division being longer than the intermediate ones to make the counting more easy Now, by means of the object-glass *c*, a tenth of an inch, when in focus of the microscope, is made to measure 50 divisions upon the scale *b*, and, consequently, each division represents $\frac{1}{500}$ or decimally 002 of an inch The image and the scale are both equally magnified by the eye-piece *d*

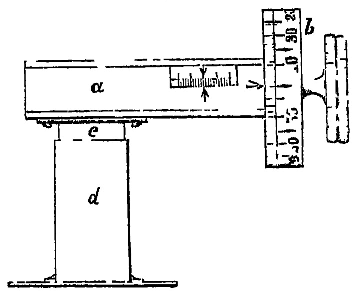
To make use of the Dynameter proceed as follows —

1 Hold up the instrument to the light and adjust the eye-piece so that the scale *b* may be distinctly seen

2 Take the external tube *a, a* between the thumb and fore finger of the left hand and place it against the eye-end of the telescope then, with the right hand, move the body of the microscope within the external tube till the image upon the eye-piece of the telescope is seen, in the field of the microscope, clear and well-defined Finally, observe how many divisions upon the scale *b* are equal to the diameter of this image, fractional parts of a division being estimated by the eye.

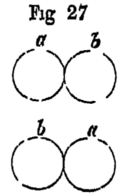
Fig 26 represents the double image Dynameter This instrument consists of a box, *a*, containing two semi-lenses, one of which is fixed and the other moveable by means of a fine micrometer-screw Whole revolutions of the screw are marked upon the side of the box, and parts of a revolution upon the micrometer head *b* *c* and *d* are sliding tubes for adjustment to focus The tube *c* contains two lenses, a convex and a concave, by which, in connexion with the semi-lenses before mentioned, a definite value in parts of an inch is given to the micrometer scale It is usual so to arrange the optical part of this instrument that five revolutions of the micrometer-screw measure 0 1 of an inch, and, as the micrometer head is divided into one hundred parts, each division upon its scale measures $\frac{1}{5000}$ or 0 0002 of an inch.

Fig 26



The phenomena observed with the double image Dynameter are the contacts, on opposite sides, of two circular discs as represented in the accompanying figure

Fig 27



Half the sum of the two readings which correspond to these phenomena will give the true

diameter If, when the images are in exact coincidence, the two scales, namely, that upon the box for whole revolutions, and that upon the micrometer head for fractional parts, are both at zero, a measure on one side only will suffice, but, as it is hardly possible for an instrument to be so nicely adjusted as to be absolutely free from *index error*, it is better in general to depend upon half the sum of the two readings

A good idea of the magnifying power of a telescope may be formed in the following manner. Let it be pointed to an object, the moon for example Then, if the observer can keep both his eyes open (this, if he find difficult at first, will, after a few trials, become sufficiently easy), he may with one of them look through the telescope at the magnified image, and, with the other, directly at the object in the heavens By a little motion of the telescope the object and image may be brought together, and a tolerably correct estimate made of the magnifying power if it do not exceed twenty or thirty times It must be observed, however, that this direction is given rather as a pleasing way of making magnifying power apparent, than as a means of measuring the amount of it, for this can only be done correctly by one of the two methods above described

The degree in which magnifying power can be made use of to advantage will in many cases depend on circumstances irrespective of the goodness of the object-glass, such, for example, as the state of the atmosphere, and the quality of the object under observation Indeed, in a general way, low and medium powers are far more useful than high ones

It remains for me only to remark, and the inexperienced will do well to keep it in mind, that the finest telescopes are frequently supposed to fail simply from the circumstance that the observer is unacquainted with the phenomenon for which he is looking

OF STANDS FOR TELESCOPES

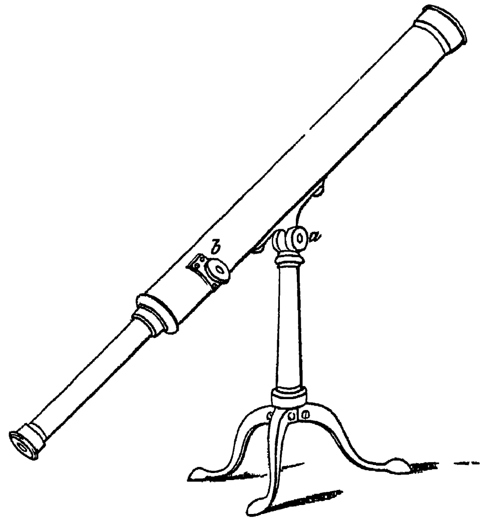
The way in which a telescope is mounted is by no means a matter of indifference. Many first-rate telescopes are little used, or used to no good purpose, for want of being firmly supported, and fitted with such mechanical means as would enable the observer to find an object and examine it at his leisure, free from the vexations and annoyances that result from fruitless attempts at managing a bad instrument. It will be far wiser, and productive of more satisfaction ultimately, to have a telescope and stand duly proportioned to each other, but of moderate dimensions, and, where practicable, placed under cover of an observatory, than to expend all one's means in the attainment of great optical power, trusting to ropes and spars for a momentary glimpse of some interesting object a few times in the course of a long summer. The opportunities wasted in this manner, would, with a well-appointed instrument, yield a plentiful harvest of useful and gratifying observations.

I now proceed to the description of several forms of Stand.

The Pillar and Claw Stand, as it is called, is that most commonly used with telescopes of from 30 to 45 inches focal length. This stand is shown at fig. 28, where it appears in its simplest form. Its object is to enable the observer to give to the telescope two distinct motions, in planes at right angles to each other; and these planes are, in the position in which the instrument usually stands, and that in which it is represented in the figure, the vertical and horizontal. This object is accomplished, with respect to the vertical motion, by means of the joint at *a*, and the horizontal motion by a conical axis carefully fitted into the capital of the pillar and secured there by a nut and screw which are not seen in the figure. If a small screw be taken out from near the top of the pillar, the Pillar and Claw Stand

capital can be removed by unscrewing, and the acting parts cleaned and lubricated when it is necessary to do so

Fig 28



The legs are made to fold by means of joints, and, the pillar being turned down parallel to the telescope tube, the whole is placed within a box of such size as to be conveniently portable

The head of the rack and pinion motion for adjustment to focus is represented at *b* In telescopes, however, which are furnished with a long range of powers, or in which a micrometer sometimes takes the place of the ordinary eye-piece, the focus adjustment does not depend on the rack and pinion motion alone, but is effected approximately by a second tube, which slides freely within that to which the rack is attached This sliding tube is called the *tail-piece*

The bodies of telescopes of this class have sometimes a conical shape given to them, being much smaller at the eye than at the object-end This is injudicious, for the only way by which such a telescope can be pointed to an object is by looking along the top and one side of the tube, and in

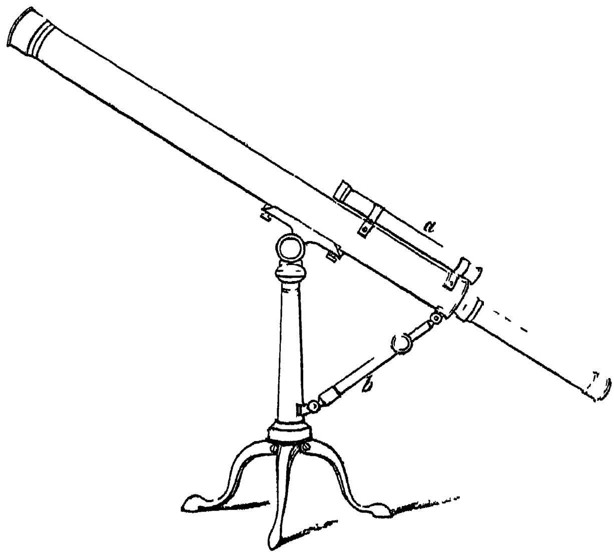
doing this the cylindrical form will be found by far the most convenient

If two eye-pieces be supplied with such a telescope, the one of lower power should be used for finding the object, and a little practice will enable an observer to leave it, when found, in such a part of the field of view, that, by the time he has changed the eye-piece, it will appear not far from the centre of the field with the higher power

The Finder

The first addition usually made to such an instrument as that just described is a Finder (*a*, fig 29) This consists of

Fig 29



a small achromatic telescope which is attached to the body of the larger one, and owes its name to the purpose it is intended to serve. The eye-piece being of very low power, the field of view is, consequently, extensive, and it will therefore be extremely easy so to direct the instrument as to render a given object visible within it, and to bring this object to the intersection of the two strong wires which are placed across it at right angles to each other. The axis of the finder, which

passes through the point of intersection of these cross wires, is, by adjustment, made parallel to the optical axis of the larger telescope, and this adjustment being perfect, a distant object which is seen in the intersection will also be seen in the field of view of the principal telescope The adjustment of the finder is generally effected by three small screws near to its eye-piece, which press against the edge of the diaphragm, to the face of which the cross wires are fixed It may be mentioned that for this adjustment it is not necessary to direct a telescope to the heavens, as a distant terrestrial object may be made use of successfully

Vertical rack motion

The vertical rack motion shown at *b* is another and useful addition to this kind of stand It consists either of two or of three tubes which slide within each other, the largest being attached by a joint to the base of the pillar and the smallest similarly secured to the eye-end of the telescope The two larger tubes slide freely, but can be fixed in any position by an embracing clamp The smallest is moveable by rack and pinion

To the vertical rack motion may be added with advantage means for enabling the observer to communicate a slow horizontal motion When this is done, and indeed generally when even no more than a vertical rack motion is added, the construction of the vertical axis of the stand differs from that previously described

Horizontal rack

The pillar in this, as in the other case, consists of an outside and inside cone, but whereas in the former the telescope was attached to an inside cone dropping into the outside one at *a* (fig 28), in the latter the telescope is attached to the outside cone which drops upon the inside one, this being firmly attached to the base of the stand Upon the lower end of this fixed inside cone a ring is made to move stiffly, and in the edge of this ring are cut teeth to which those of an endless screw attached to the revolving outside cone adapt When therefore the observer wishes to give a great or rapid horizontal motion, he has only to apply to the telescope force sufficient to cause the outside cone, together with the ring, to revolve upon the inside one, whereas, whilst giving the slow motion by means

of the endless screw, the ring, in consequence of the friction, remains attached to the immoveable inside cone

Hook's Joint

To the endless screw applies a handle and universal joint (fig 30), commonly called the Hook's Joint from the name of its inventor, a contrivance so well known as to render a detailed description unnecessary

Fig 30

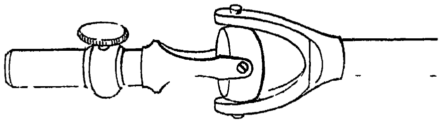
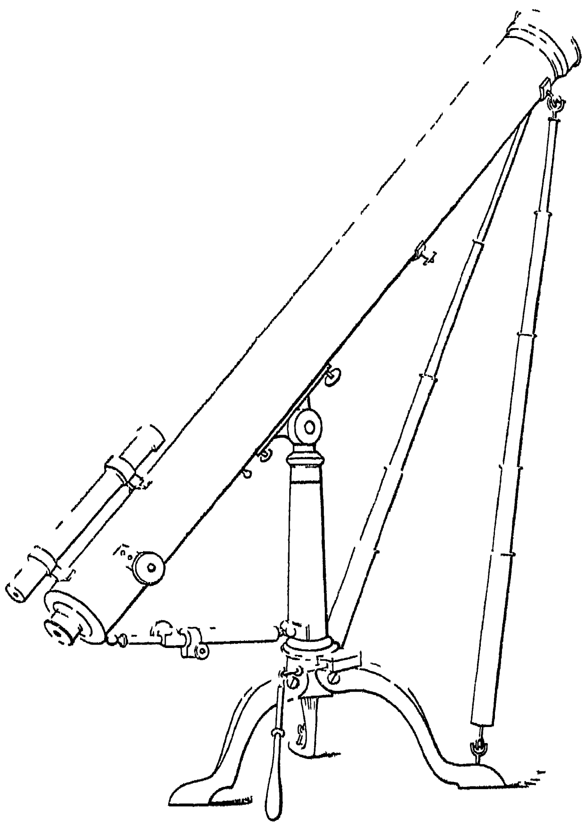


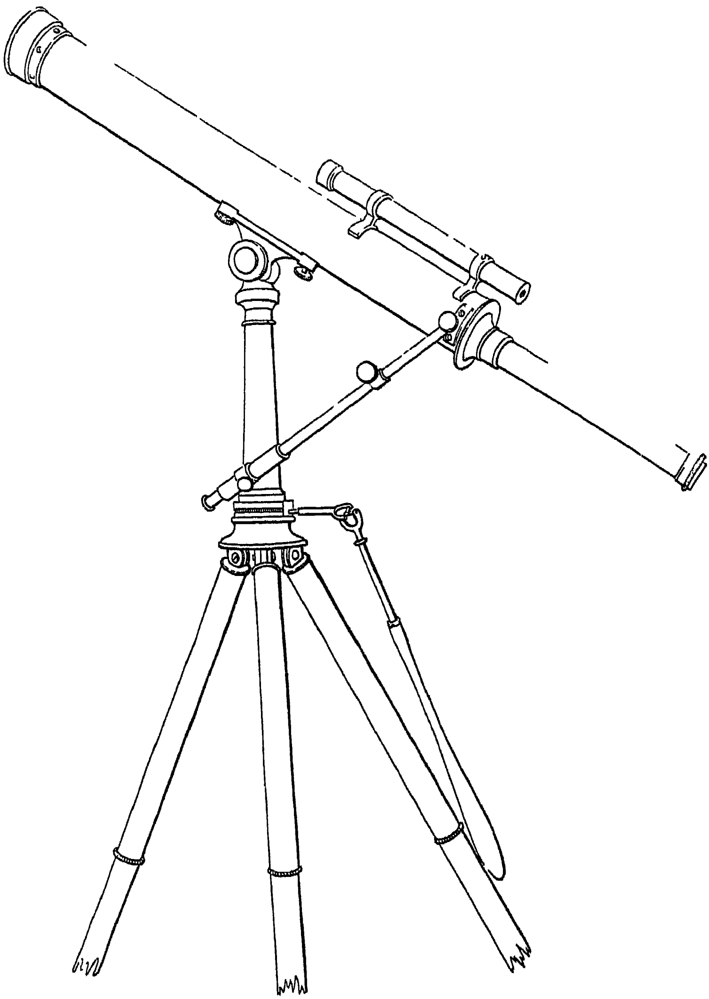
Fig 31



By means of the two slow motions the observer may follow a star much more perfectly and with greater facility

than he would by merely pressing the telescope forward by hand

Fig 32



Steadying rods

An additional degree of firmness is sometimes given to telescopes upon ordinary stands by furnishing them with steadying rods, generally two in number, each rod consisting

of three or more tubes sliding one within another, and terminating at its ends in universal joints One of these joints is attached to the object-end of the telescope and the other to the foot of the stand, as shown by fig 31 If the length of a telescope exceed four feet such rods are almost indispensable

Of the instrument represented in fig 32, it may suffice to state that it is especially adapted to the purposes of the traveller by whom considerable optical power with portability may be required

The focal length of the object-glass is about thirty, with a clear aperture of $2\frac{3}{4}$ inches The legs are formed of tubes slipping within each other When drawn out they are fixed at their greater length by turning the interior tube from right to left, until it abuts against a shoulder within the exterior one

Varley's Stand, shown at fig 33, is well adapted to the purposes both of the optician and the amateur It is inexpensive, firm, convenient in use, and can be so arranged, that two telescopes, between which a direct comparison is to be made, can be placed upon it side by side Varley's Stand

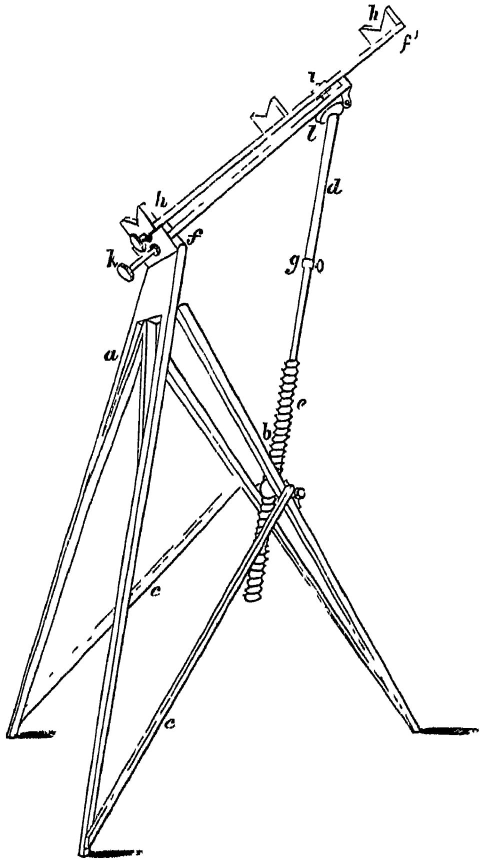
The frames *a* and *b* are connected by a pair of strong hinges, and, when open, are braced by the bars *c*, *c*, which are fastened to *b* by finger-screws The same screws, when the frames are folded together, serve to hold the bracing bars *c*, *c* against the sides of the frame *a* The elevating stage *f*, *f'* moves upon hinge-joints, and is supported at any altitude by the prop *d e* This prop is adjustible, or can be altered in length, first, by sliding an exterior tube *d* upon a cylinder within it, and fixing it at the required place by the embracing clamp *g*, and, secondly, by turning the screw *e*, which is a prolongation of the interior cylinder, within the socket through which it passes.

A cradle *h h* upon an axis *i* turns in a plane parallel to *f*, *f'*, and in this cradle the telescope is laid and secured by leathern straps

At *k* are two slow motions, both within convenient reach

of the observer's hand, of which the upper one is a rack and pinion for the purpose of giving a lateral motion to the cradle,

Fig 33



and the lower one slightly alters the elevation by varying the length of the side $f\ l$ of the triangle $f\ b\ l$ These two motions give to an observer the power of following a star in the same manner as it is done by a combination of the vertical and horizontal motions in a pillar and claw stand

THE EQUATORIAL

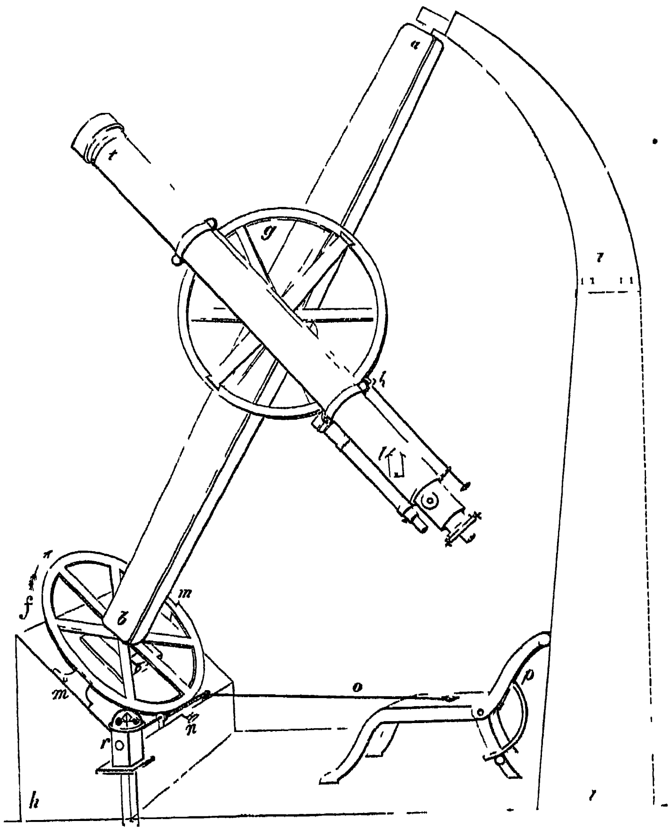
Having now described such forms of Stand as are in common use for occasional inspection of celestial objects, and for observations of such phenomena as eclipses of Jupiter's satellites and occultations of stars and planets by the moon, we pass on to the Equatorial

To a spectator at the earth's surface, the heavens appear to revolve on an axis whose inclination to the horizon is equal to the latitude of the place, a phenomenon produced by the revolution of the earth itself, and for a detailed explanation of which I may refer the reader to Woodhouse's 'Astronomy,' vol i cap 1

A point in the axis of rotation, infinitely distant from the spectator as are celestial objects in general, would be stationary, and other points would appear to describe circles increasing in magnitude with an increasing angular distance from the first point (called the pole) up to a distance of 90° or a quadrant, after which they would again diminish towards the opposite pole. Now if we could, conveniently, place the Pillar and Claw Stand already described in a position in which the axis of motion within the pillar (the horizontal motion in the usual position) should coincide with the axis of rotation of the heavens, *i e* give it an inclination to the horizon equal to the latitude of the place, it is clear that by a single motion of the telescope, viz one of rotation about the said axis, the line of sight would be made to trace upon the celestial sphere circles corresponding to those in which the heavenly bodies appear to move, these circles increasing as, by moving the telescope upon the second axis (that on which the vertical motion is, in the usual position of the stand, performed), we increase the angle between the line of sight and

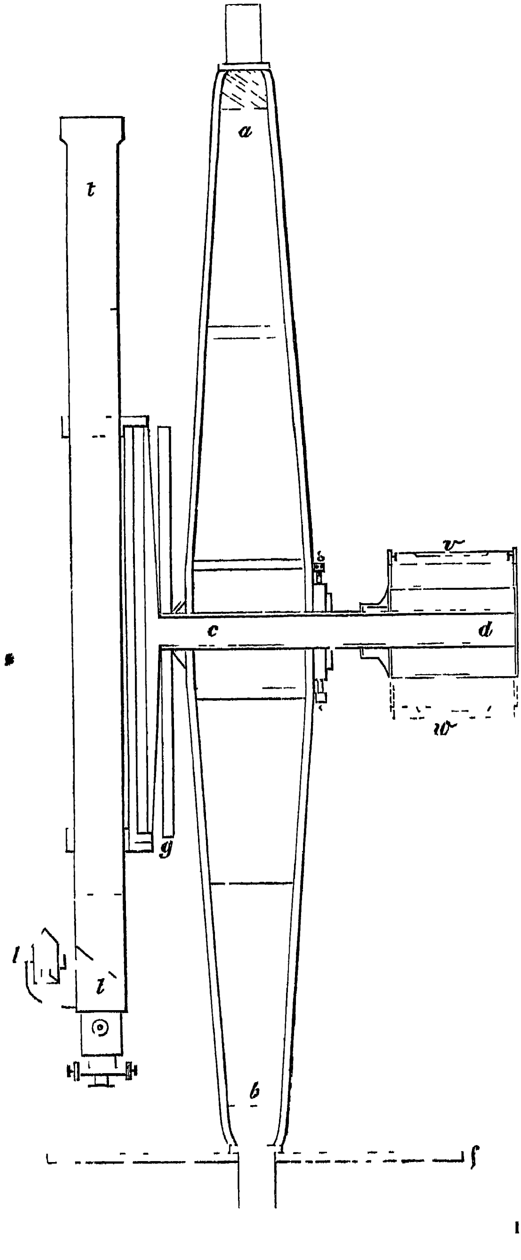
the first axis, just as the circles which the heavenly bodies themselves appear to describe increase with increasing polar distance of the objects Furthermore, it will be evident that the angle between the line of sight and the first axis must be

Fig 31



equal to the angular polar distance of the object observed; and that the angle through which the plane containing the line of sight and the said axis would revolve in following a

Fig 35

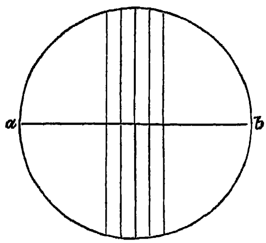


fixed star between one point of time and another, must, when converted into hours, minutes and seconds, represent the sidereal time elapsed

By placing the Pillar and Claw Stand in the position just described, we should, in fact, convert it into an Equatorial Stand But, in the Equatorial Instrument, properly so called, the axes are constructed and supported in such a manner as to ensure to the telescope a degree of steadiness proportionate to the delicacy of the observations to which it may be applied, and they likewise have divided circles attached to them, which may be used either to measure differences of Right Ascension and Polar Distance, or to direct the telescope upon an object whose position is given in the Tables. We proceed to describe the instrument in detail, selecting for this purpose the form represented in perspective by fig 34, and in section by fig 35, the same parts being indicated by the same letters

a b, *c d* represent the axes, of which *a b*, called the Polar Axis, is directed towards the pole of the heavens, and is supported in this position by stone piers *h* and *i*, the curved portion only, *i'*, of the latter being generally of cast iron This axis terminates in cylindrical pivots, which rest in Ys, and one of these Ys, commonly the lower, is provided with means of adjustment, in order that the direction of the axis may be slightly altered when necessary This contrivance cannot be shown in the figure, but a similar one, represented in fig 35, will be alluded to presently *c d* represents the declination axis This passes through the polar axis, and rests in collars, and, as the two axes should be at right angles to one another, the collar at the end *d* is adjustible by means of the screws *s s* The collar in which the end *c* revolves is held by pivots, which allow to it freedom of motion through a small arc, in order that the adjustment may be performed without producing any strain The telescope, *t t*, is fixed at right angles to the declination axis, and firmly braced in that position, its eye-end is provided with means for the adjustment of the line of sight

Fig 36

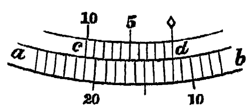


These consist of a Transit Eye-piece, containing a system of cross wires shown at fig 36, the line of sight passing through the intersection of the middle vertical with the horizontal wire, and the whole system being moveable to the right or left by screws at *a* and *b*

The angle between the line of sight and the polar axis is measured on the circle *g*, called the declination circle This is divided into degrees and fractional parts, and these are further subdivided to any required degree of minuteness by opposite *verniers* * upon an index-plate carried round with the telescope When the line of sight is parallel to the polar axis, or, in other words, is directed to the pole, the index division upon each vernier should point to zero, and in order that it may be made to do so, means for adjustment are generally applied to the ver-

* Let *a b* (fig 37) be a scale of equal parts, or an arc of a graduated circle, and let it be required to construct a *vernier* by which the position of zero, upon *c d*, a moveable index, shall be ascertainable to one-tenth part of a space upon the scale *a b* Take upon *c d* a length equal to nine parts upon *a b*, and divide it into ten Then, since each space upon *c d* is equal to nine-tenths of one upon *a b*, it follows that to carry the zero forward one-tenth of a space upon *a b*, we have merely to make the line next in advance of zero (or the first division upon the vernier) coincide with the next forward division upon the scale *a b* In like manner two-tenths will be indicated by coincidence of the second division upon the vernier, and the corresponding division upon the scale, and so on to the end

Fig 37



The same effect will be produced if a space equal to eleven parts upon *a b* be divided into ten upon *c d* The first is called a *leading* and the second a *following* vernier

niers themselves. A clamp and tangent screw near to *k* give the observer the power of fixing the telescope at any required polar distance, or of moving it slowly through an arc of small extent.

The angle through which the plane containing the line of sight and the polar axis revolves is measured on the circle *f*, called the hour-circle. This circle is divided to show portions of time, the spaces upon it being 1440 in number, and each, therefore, representing a single minute. This is carried round with the polar axis *. At *m*, *m'*, fixed to the pier, are two verniers, by which a reading may be made to a single second. The hours are marked from one to twenty-four. The zero divisions upon the verniers should point to XII. and XXIV. when the declination axis is horizontal, and in order that they may be made to do so, means for adjustment are applied to the verniers themselves.

The edge of the hour-circle is racked or cut into teeth corresponding with the threads of an endless screw, which forms part of a clamp at *n*, and serves to give a slow motion to the instrument. Such a motion is communicated by means of a rod *o*, terminating in an universal joint, and this may be acted upon either by the observer himself, or, in case the motion is required to be uniform (as in following an object for

* In some Equatorials of the highest class the hour-circle is not permanently fixed to the polar axis, but turns freely upon the lower pivot, and is kept in motion by the clock at the rate of one revolution in twenty-four sidereal hours. The hours increase in the order of right ascension, and they are pointed to by an index fixed to the pier.

A second index is fixed to the polar axis, and is furnished with a clamp, by which it can be firmly attached to any part of the hour-circle, and, when so fixed, be carried round by the clock-work. The positions of the indices are so arranged that they point to the same division upon the hour-circle when the telescope is in the meridian, and if they then indicate the sidereal time, or right ascension of the meridian, it will be evident that the second index will, when the telescope is in another position, indicate the right ascension of that point of the heavens to which the line of sight is directed. This improvement was introduced by the present Astronomer Royal, and first applied to the Northumberland Equatorial at the Cambridge Observatory.

example), by a clock But, in order that the two actions may subsist independently one of the other, it is usual to attach two such rods, one to each end of the screw, communicating respectively with the observer and the clock This arrangement is shown in the figure. This screw is so mounted as to admit of its threads being detached from the edge of the circle, when the telescope is to be moved rapidly through a large arc

The machinery of the clock *r* just now mentioned as communicating to the instrument an uniform motion equivalent to the apparent motion of the heavens, is extremely simple The moving power is supplied by a weight descending below the floor of the observatory, and the action regulated by a centrifugal pendulum resembling in some respects the governor of a steam-engine The separation of the balls brings a break into action, which prevents acceleration by applying the needful amount of friction*. A final adjustment to time is made by a micrometer-screw seen at the back of the clock, and there are contrivances as well for stopping the clock instantaneously as for attaching it to, or detaching it from, the tangent screw *n*

In order that the wires of the Transit Eye-Piece, or the spider's threads of the Position Micrometer, to be described hereafter, may be seen at night, the field of view requires to be illuminated This is accomplished by a lantern, *l*, which remains erect whatever be the position of the telescope The light passes through an aperture in the tube, and, falling upon a reflector, which is perforated in order that it may not obstruct rays in their passage from the object-glass, is diffused over the field of view The aperture in the tube through which the light passes, can be instantaneously contracted or altogether closed at the observer's pleasure, and, by this means, the amount of illumination may be adapted to the brilliancy or faintness of the object under observation It has been noticed that some stars are best seen through a

* Refer to Monthly Notices of Royal Astronomical Society, vol iii p 40

red illumination This, for the occasion, is produced by placing a disc of ruby glass between the lantern and the reflector.

A Finder is an useful addition, and is generally attached to the telescope of an instrument of this class

A weight at the end of the declination axis is an equipoise to the telescope, and those parts of the instrument which are placed with it on the opposite side of the polar axis Upon this weight are fixed two supports carrying cylindrical pivots, with adjustments at right angles to each other, and to these pivots is suspended a spirit-level, *v*, by means of which the declination axis may be set horizontal

Adjustments of the Equatorial

The conditions of adjustment in an Equatorial, irrespective of the position of the polar axis, are as follows —

1st That the polar and declination axes be at right angles to each other

2nd That the optical axis of the telescope, or line of sight*, be at right angles to the declination axis

3rd That the verniers of the declination circle read 0 when the line of sight and polar axis are parallel†

4th That the verniers of the hour-circle read 0 when the declination axis is horizontal

1st. To set the declination axis at right angles to the polar axis

Place the spirit-level *v* upon the cylindrical pivots on which it turns, and, by moving the hour-circle, bring the air-bubble to the middle of the opening in the tube Now, lift it from the pivots, reverse and replace it If the level be in adjustment, the air-bubble will resume its former position in the middle of the opening If it do not so, then, correct half the error by moving the adjustible inverted Y at one end of the tube in which the spirit-level is fixed, and the remaining half by moving the hour-circle If the spirit-level have a graduated scale upon it, and the error lie within the limit of the divisions, it is easy at once to apply the needful correction, but,

* Sometimes called the line of collimation

† This supposes the verniers to show polar distance

however this may be, the above operation must be repeated until the adjustment is accomplished. Then, the hour-circle being clamped, turn the instrument half round on the declination axis, so that the spirit-level may be brought into the position shown by the dotted lines at *w*. If the bubble be not now, as before, in the middle of the opening, correct half the difference by raising or depressing one of the pivots upon which the spirit-level turns, and half by giving motion to the hour-circle. Finally, turn the instrument on the declination axis through an angle of ninety degrees, and should the air-bubble have changed its position, it must be made to resume it by means of the pair of screws left untouched in the first and second adjustments.

When these corrections have been perfectly made, an entire revolution of the declination axis will cause no disturbance in the position of the air-bubble, and it now remains only to turn the instrument half round on the polar axis, and to correct half the deviation of the spirit-level by means of the screws *ss*, taking care to release those upon one side before those on the opposite side are pressed forward,—a remark applicable to all similar adjustments.

2nd. To set the line of sight at right angles to the declination axis.

Screw in the Transit Eye-Piece, the wire-plate, or diaphragm, of which is shown at fig. 36, and turn it round until a star runs along the declination wire *a b*. Set the telescope a little in advance of the star, clamp the hour-circle, read the verniers, and note, by a sidereal clock, the time at which the star passes over the middle vertical (or meridian) wire. Turn the instrument half round on the polar axis, and direct the telescope again a little in advance of the same object. Read the verniers and observe the time of passage as before. If the adjustment be correct, the interval of time between the two observations will agree exactly with the difference between the two readings upon the hour-circle. If it be not so, correct to the extent of half the difference by means of the proper screws which act upon the diaphragm. If a very

distant object be visible from the observatory, this may be used instead of an observation of a heavenly body.

3rd. To make the verniers of the declination-circle read zero when the line of sight and polar axis are parallel.

Direct the declination wire *a b* (fig. 36) to any object in the heavens, and read the verniers for polar distance or declination as the case may be. Turn the instrument half round on the polar axis, re-direct the telescope, and read the verniers as before. Half the difference of the readings will be an index error, which, with the proper sign, may either be applied as such to the observations, or corrected by moving the verniers upon the index bar. If the quantity be so small as not to affect the operation of the instrument in finding an object, it is recommended rather to apply it in the form of a correction than to attempt its removal by disturbing the verniers.

4th. To make the verniers of the hour-circle read 0 when the declination axis is horizontal.

Having brought the declination axis to the horizontal position as was done in the course of the first adjustment, set the zero divisions of the verniers to coincidence with the divisions marking XII and XXIV hours respectively.

These several adjustments having been carefully and satisfactorily gone through, the final rectification with respect to the heavens is not a difficult operation.

It is presumed that in the erection of an instrument of this kind, the piers have been so placed that the polar axis when adjusted may be nearly central with respect to the lower one, and likewise that the Ys have been fixed to the piers in positions such that the final adjustments may be within the range of the proper screws*. The operator, having by some pre-

* A meridian line sufficiently exact for the erection of the piers may be obtained by the shadow of a plumb-line at apparent noon, or by bisecting the angle between two shadows observed at equal intervals before and after it. This supposes the time to be known at least as correctly as it is usually given by a good watch; but, in ignorance of the time, the old expedient of equal altitudes may be resorted to. This consists in placing an upright pin in the centre of several concentric

paratory trials assured himself upon this point, may proceed in the following manner

1st To give to the polar axis an elevation equal to the latitude of the place

Select from the catalogue in the Nautical Almanac any standard star which may happen to be near the meridian, and set the verniers of the declination-circle to the polar distance corrected for refraction Then, if the star does not run along the declination-wire, it must be made to do so by elevating or depressing the lower end of the polar axis, as the case may require

2nd To set the polar axis in the meridian

Direct the telescope upon a known star about six hours from the meridian east or west, and read the verniers of the declination-circle. This reading, corrected for refraction*, should be the star's polar distance as given in the Tables But, if the star be to the east of the meridian, and its tabular polar distance exceed the instrumental reading, the lower pivot of the polar axis will be to the west of its true place, and must be moved accordingly If the tabular polar distance be less than the instrumental reading, the pivot must be moved in the opposite direction

Should the star observed be to the west of the meridian, the effects of an erroneous position of the polar axis will be reversed, and the adjustments must be made to correspond Operations 1 and 2 must be repeated in order until the results are satisfactory

Another method of performing adjustment 2 may be briefly mentioned Set the declination axis horizontal, and by means of the adjusting screws which act upon the lower Y make the middle vertical wire bisect a star near the equator at the moment of its passage over the meridian Should

circles drawn upon a horizontal plane, and making a mark where the *top* of the shadow of the pin falls on each circle before and after noon The bisections of the intercepted arcs should be in a diameter common to all the circles, which diameter will be the meridian

* Refer to Introduction to Greenwich Observations for 1846, p lxxiv

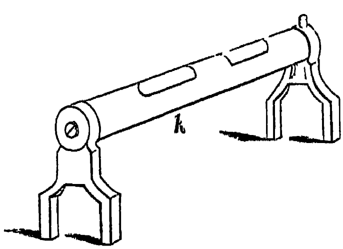
the observer have no meridional instrument by which he can obtain time correctly, he may observe with the Equatorial the passage of a star near the zenith, and use the time thus obtained for adjusting on the Equatorial star The operation should be repeated until the results are satisfactory, and when this is the case adjustment 1 may be completed with all necessary accuracy

In conclusion. The verniers of the hour-circle will require a final adjustment after the rectification of the polar axis is complete For this purpose let the declination axis be carefully levelled, and the verniers moved into their respective places by the adjusting screws provided for that purpose

Different forms of Equatorial

The instrument, the construction and adjustment of which have just been explained, is known as Sisson's Equatorial, and it has been selected for the purpose of illustration on account of its simplicity, and the consequent ease with which all its parts can be represented and distinctly treated It now remains to notice, briefly, such other forms of Equatorial instrument as are in common use

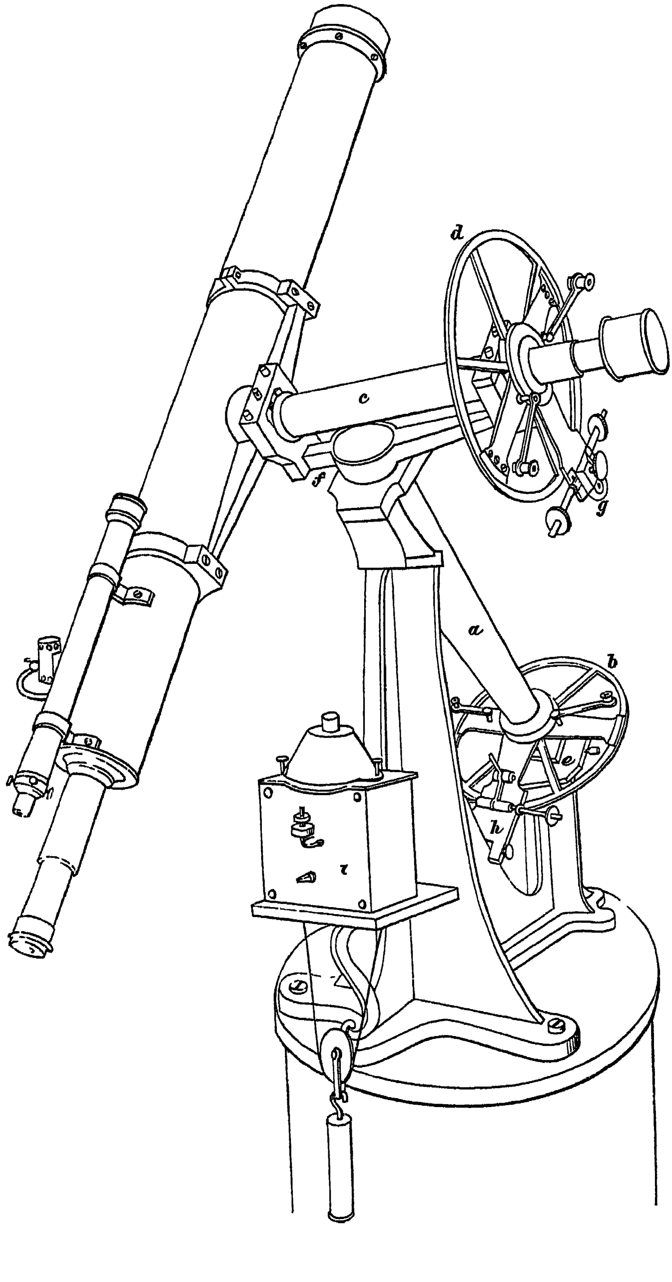
Fig 38 represents Fraunhofer's form of Equatorial, in which *a* is the polar axis and *b* the attached hour-circle, *c* the declination axis and *d* its attached circle Means for the adjustment of the polar axis are provided at *e*, and of the declination axis at *f* The zero of the verniers is adjustible by means of opposite screws at *g* and *h* respectively; *i* is the driving clock, which is connected with the hour-circle by a rod not seen in the figure



The spirit-level, *k*, applies to cylindrical parts just within the bearings of the declination axis, and is more direct and effective in its action than the one previously described The whole is supported upon a cast-iron stand

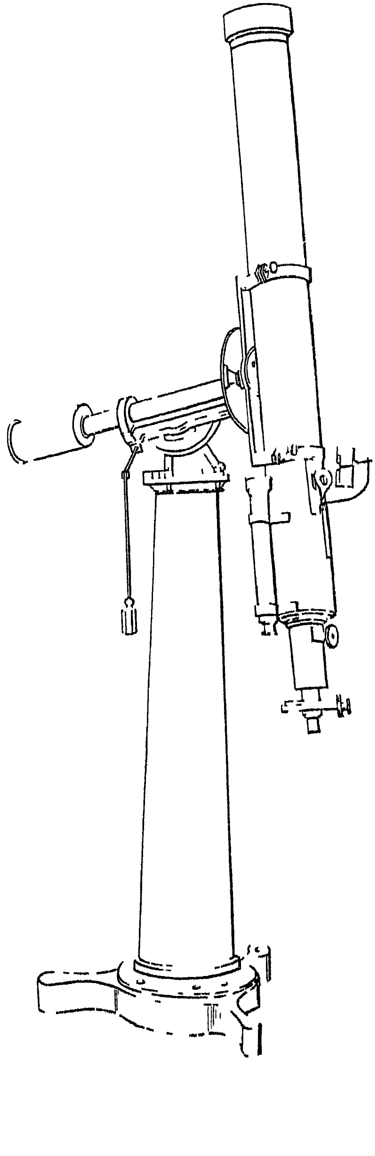
The principal advantage attending this form of construction is, that the telescope will reach every part of the heavens

Fig. 38



without interruption, whereas, in Sisson's form, it will be seen that the upper support of the polar axis must interfere to some extent with observation of objects about and below the pole It is to be observed, likewise, that this instrument is more easily erected than the polar axis of Sisson, which

Fig 39

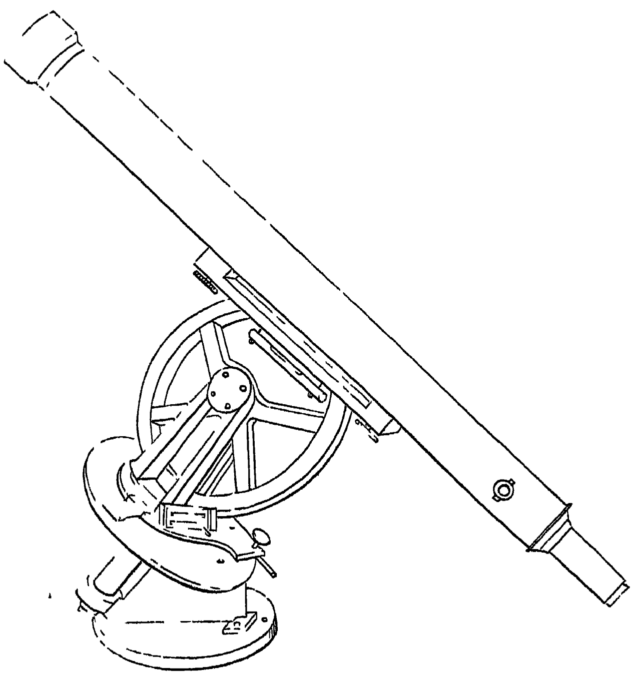


requires much careful preparation in order to ensure its being within the limits of the adjustments, whereas, in this case, a simple pedestal of stone or brick, or if the instrument be not of large size, a strong and firmly braced wooden stand, is all that is required

Fig 39 represents an instrument of the same form in so far as the position of the telescope is concerned, but the hour- and declination-circles are differently placed, and the clamps, being near the telescope, act most effectively and with perfect freedom from torsion, an effect against which, in the last-described instrument, it is necessary to guard, by giving great strength to the polar and declination axes The adjustments for the elevation and meridional position of the polar axis are upon the top of the column In other respects the figure will be sufficiently explanatory

Fig 40 represents an Equatorial much used for occasional observation of celestial phenomena in some regions of the

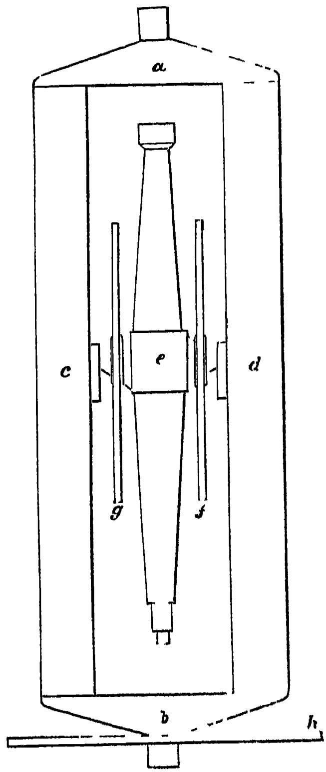
Fig 40



heavens. From the construction of this instrument, it will be seen that the telescope cannot be directed upon objects about the zenith or pole: but, the frame, which constitutes the stand, being of wood, it may be easily removed from one place to another, and set approximately in position; and it is therefore well adapted to observation of such phenomena as occultations, or the inspection of objects about the zodiacal region. Thence it has been called the Zodiacal Equatorial.

Fig. 41 is a longitudinal section of an instrument in which, like Sisson's, the length of the polar axis exceeds that of the

Fig. 41.



telescope. This polar axis, however, instead of being formed of a single shaft, consists of an open frame, so constructed

that the telescope may occupy a central position within it, a circumstance favourable to the general symmetry of the instrument, and advantageous in some respects with reference to the openings through the dome by which the instrument is covered

The partial interruption to vision at and below the pole is a fault for which there is no remedy

a b c d represents the polar axis, in which *a* and *b* are two similar cast metal frames, each having a cylindrical pivot in its centre, *c* and *d* form the sides, and are either an open firmly braced framework of metal or wood, or hollow cones, or semi-cylinders, strengthened by diaphragms judiciously arranged within them These sides are securely fixed to the end frames, and altogether form an axis free to a great extent from flexure or torsion The telescope and declination axis *e* have the form of an ordinary Transit Instrument, and the support at one end of the axis is adjustable, in order that the two axes may be placed at right angles to one another The declination circle is shown at *f*, and this is counterpoised by a similar circle, *g*, upon the edge of which the clamp and tangent screw are usually made to act The hour-circle, *h*, is either immoveably fixed to the lower pivot, or turning freely upon it, can be clamped in any position for the purpose explained in the note at the foot of page 38 The minor appliances are generally similar to those of Sisson's Equatorial, and to treat of them in this place would consequently be a needless repetition This form of instrument has been adopted by the Astronomer Royal for some of the largest works of the kind that have yet been executed in this country, of which two examples are the Northumberland Equatorial at Cambridge and that in the Observatory at Liverpool

The Equatorial Instrument, as usually constructed, is designed for a particular latitude, or, in other words, the inclination of the polar axis does not admit of variation through any considerable extent of arc Instruments, however, are made, in which the polar axis moves through an entire quadrant, and thus admits of rectification for any latitude what-

ever This kind is appropriately termed the Universal Equatorial Sisson's instrument, indeed, by a due regulation of the height of the piers, can have any required inclination given to its polar axis, and so far it is universal, but its removal and re-erection would be attended with too much labour and expense to make it, in that sense, at all useful to the scientific traveller

The Universal Equatorial is shown at fig 42 All the parts above the hour-circle *a* so closely resemble the corresponding parts of the instrument represented at fig 38, that they will be recognised by the reader without further explanation

The whole instrument turns upon the latitude axis *c*, to which is attached a graduated quadrant indicating the elevation of the polar axis E is an equipoise for the parts of the instrument situated above the axis *c*

Two spirit-levels are fixed upon the base at *e* and *f* These, when properly adjusted, serve to indicate the general correctness of the instrument with respect to horizontality, and prevent the necessity for applying the level to the declination axis so frequently as might otherwise be thought desirable

The instrument is levelled by means of the feet screws, and three plates are given for them to rest upon In one of these plates an adjustment is introduced, by which a small degree of motion in azimuth may be given to the whole instrument This serves for the final rectification to the meridian

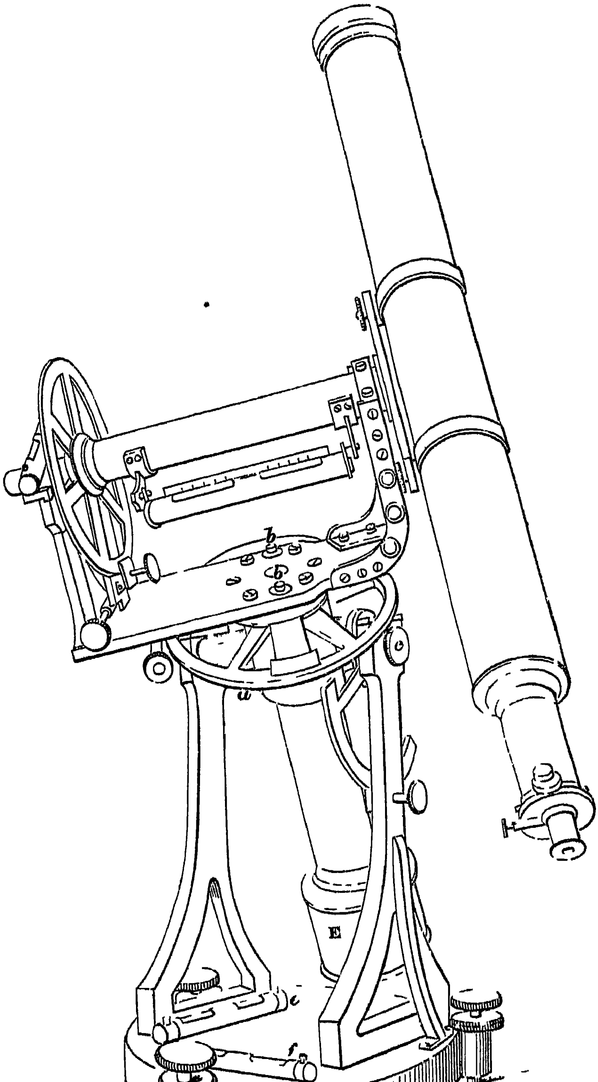
To adjust and rectify the instrument for observation

Place it upon the pedestal, and, with the verniers of the hour-circle set to XII and XXIV, turn the whole round till the telescope points to the meridian as nearly as can be ascertained Set the latitude quadrant to 90°, and by means of the feet screws bring the levels *e* and *f* to the middle of their respective openings

Apply the level to the declination axis, and by reversion, as before directed, adjust it within itself

Turn twelve hours and correct the declination axis, half by the adjustment of one of the Y's in which it rests, and half by one of the foot screws

Fig 12



Turn six hours and do the same by means of the meridian foot screw alone, and the polar axis will now perform an entire revolution with no sensible disturbance of the axis-level In this state of things the levels *e* and *f* may be finally adjusted by the screws at their ends respectively

To correct the zero of declination

Take the altitude or zenith distance of any distant object, turn twelve hours and repeat the observation Half the sum will be the true altitude or zenith distance, to which reading the verniers may be set by their proper adjusting screws

The same distant mark will serve for an approximate adjustment of the line of collimation, having due regard to the eccentricity of the telescope, but this adjustment should be finally corrected by reference to the heavens as before directed, in page 41

To correct the verniers of the hour-circle.

Place the polar axis horizontal Do the same with the declination axis by means of the spirit-level, and set the verniers to XII and XXIV. hours These verniers are held by the screws *b b*

If the polar axis be now set to the latitude of the place, the instrument is rectified in every respect except as regards its final meridional position, and this last adjustment may be performed by either of the methods already explained.

If the time and the latitude of the place be known, such an instrument can be placed pretty nearly in the meridian in the following manner —

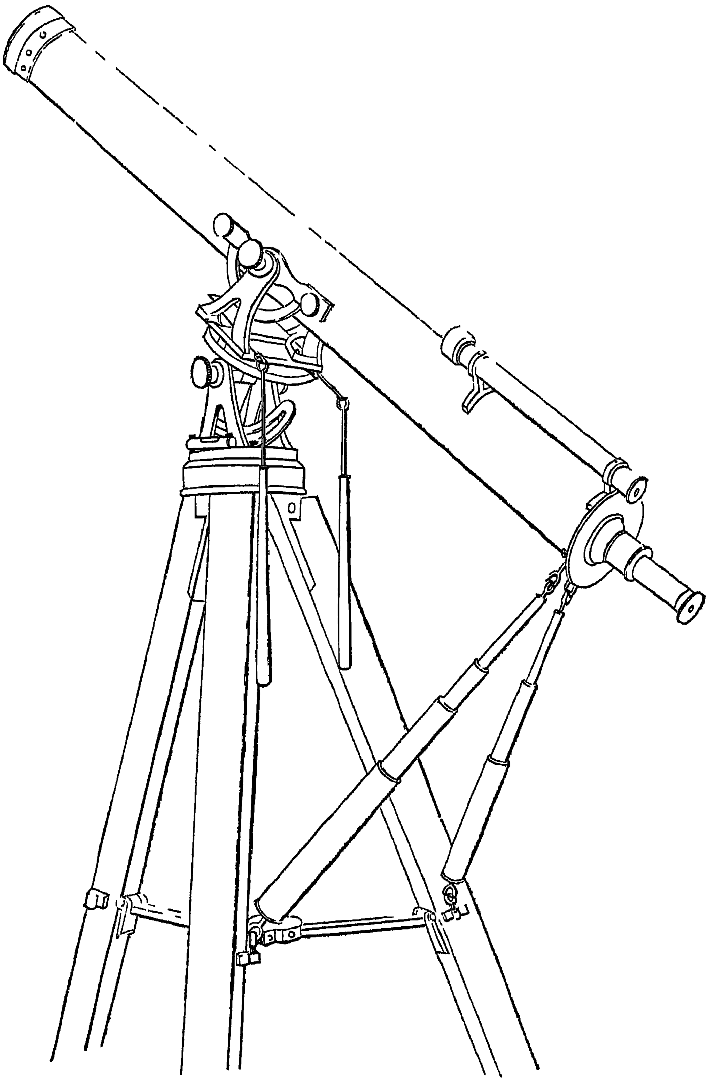
1st Elevate the polar axis to the latitude of the place.

2nd Set to the declination of the object

3rd Compute the hour-angle, or distance of the object from the meridian, and set the hour-circle verniers accordingly

4th Turn the entire instrument round upon the feet screws, having regard to the spirit-levels, until the object appears in the centre of the field of view, and the instrument will then be found so nearly rectified that the telescope can be directed to any object at pleasure

Fig 43



A vertical axis upon which the whole instrument may revolve would much facilitate this method of fixing the Universal Equatorial, but it is seldom applied on account of its increasing the weight and expense of the instrument, at the same time that it renders it less steady.

Fig 43 is a combination of the Zodiacal and Universal Equatorials, and its several parts will be evident from an inspection of the figure.

Application of the Equatorial

I have finally to mention the several purposes to which an Equatorial may be directed

Time is the first requisite of the practical astronomer, and this, in the absence of a Transit Instrument, may be obtained approximately by means of the instrument under consideration The following would be the mode of proceeding

Having attended carefully to the adjustment of the declination axis, bring the instrument to the position corresponding to zero (24 hours) upon the hour-circle, and there clamp it If the adjustments are perfect, the line of sight will now, when the telescope is made to revolve upon the declination axis, move in the plane of the meridian, and the instrument may be used as a transit Should there be a small deviation from the meridional plane, it must be found by means of observations of high and low stars, and corrected for by the usual methods†

The sidereal time being known, the telescope may be pointed to an object in the following manner Take from the Catalogue the declination (or polar distance as the case may require) of the object, and set the verniers of the declination-circle accordingly Next take its right ascension, subtract this from the right ascension of the meridian plus 24 hours, when the latter is less than the former, *i e* when the star is to the east of the meridian, and set the verniers of the hour-circle to the resulting difference The star should then be seen in the field of view

If the star be near the horizon, its place will be considerably affected by refraction Under such circumstances the

† Consult Penny Cyclopædia, articles 'Transit' and 'Equatorial

observer should use a low power for finding and bringing an object to the centre of the field of view, applying afterwards such other power as he may find expedient

The reverse of the process employed in finding an object, the place of which is known, will give the place of an object before unknown It must however be mentioned, that an equatorial, applied in this way, especially if turned a considerable distance from the meridian, will give places approximately only, and, if greater exactness be required, the instrument must be used differentially, that is, the place of the unknown object must be determined with reference to a known one in its immediate vicinity in order that the results may be as little affected as possible by flexure of the telescope, or other disturbing causes consequent on change of position

Having directed the telescope to the object, a comet for example, and secured both the clamps, observe the time of its passage over the meridian-wires, and read the polar distance from the declination-circle Leave the hour-circle undisturbed, and, having set the declination-circle for a known star, following, and not very far from the unknown object, await its arrival, and observe the time of passage and polar distance as before* It will be obvious that the difference between the observed times of passage will be the difference in right ascension, and the difference between the readings of the declination-circle the difference of polar distance of the two objects After an observation sufficient for determining the place of the unknown object with such accuracy that the observer will be able to find it again, the star of comparison may either precede or follow indifferently If the observer have any doubt about the state of adjustment of his instrument, the polar axis should be turned through 12 hours, and the above operation repeated This and other expedients will present themselves by degrees to one who diligently occupies himself with this kind of work.

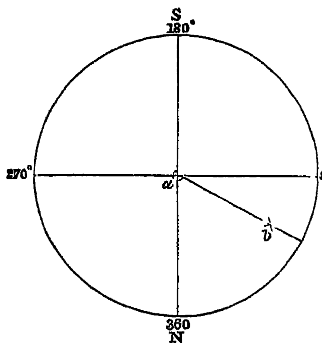
* In making these observations, the Micrometer may be used with advantage

Of all inquiries, however, in which the possessor of an equatorial can be engaged, the examination and measuring of double and multiple stars is by far the most interesting It may be pursued whenever the weather permits, and the observations, if made with ordinary care, and with an instrument of sufficient power*, will be extremely valuable

By an observation of a double star, we determine the *position* and *distance* of the objects which compose it The first is the arc intercepted between the northern point of the meridian of the larger of the component stars (which is supposed to be in the centre) and a line passing through the centres of the two, and the last is the angular distance between the two

Let the space included within the circle of fig 44 represent

Fig 44



the field of a telescope, and NS the meridian passing through the star *a*, the other component being *b* Let the circumference be divided into 360°, commencing at the north point and increasing in the order represented in the figure Then the angle N *a* *b* is the angle of position† The distance is measured

* A large proportion of the double stars may be well observed with a telescope of four inches aperture

† This is according to Sir John Herschel's nomenclature, now pretty generally adopted For information concerning the difference between this and that of Sir W Herschel, and for other exceedingly useful matter connected with this subject, the reader is referred to the "Companion to the Maps of the Stars," by A De Morgan Baldwin and Co, 1836

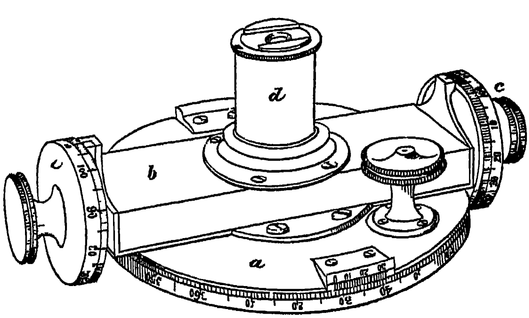
upon the line *a b*, and this, as well as the position, is determined by means of either the parallel line or the double image micrometer, appendages which shall now be briefly described

Parallel Line Position Micrometer

The Parallel Line Position Micrometer is shown at fig 45: *a* is the position-circle formed of two plates, one of which may be attached to the eye-end of the telescope by means of an adapting screw, and the second turns freely upon the first A hole through the centres allows the cone of rays from the object-glass to pass to the diaphragm

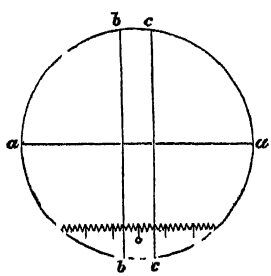
The edge of the fixed plate is graduated and numbered from 0 to 360, in the order represented at fig 44 Two verniers upon the moveable, or index plate, read each to one

Fig 45



minute of arc, and this plate is carried round by rack and pinion motion Upon the index plate is a parallel box *b*, and

Fig 46



this carries within it a system of lines, of which one, *a a* (fig 46), called the position-line, is fixed, and two others, *b b*, *c c*, at right angles to it, are moveable. Each of these is attached to a micrometer-screw, of which the milled heads and circular scales *c c* (fig 45) project beyond the circumference of the position-circle, and each of the circular scales, by which the hundredth part of a revolution is shown, turns upon its screw to admit of adjustment to zero. The entire revolutions of the screw are indicated by the notched scale seen within the field of view (fig 46). The zero division of this scale is distinguished by its terminating in a circular hole, and when the two lines coincide in the middle of this division the zero lines upon the circular scales should coincide with their respective indices. They may be made to do so, when needful, by holding the milled head firmly with one hand, and with the other turning the scale round to the required position.

Adjustment of Micrometer

Previous to using the instrument for the determination of the position and distance of a double star the following steps will be necessary:

1st. Set the verniers to 360° and 180° upon the position circle, and turn the entire micrometer round within the eye-end of the telescope till a star runs along the line *b b* or *c c*. The position wire and zero of the circle will then be in adjustment. It is almost needless to remark that this operation will have to be repeated whenever the micrometer is replaced after removal.

2nd. To determine the value (in arc) of the revolutions of the micrometer-screws.

By means of the rack and pinion motion set the verniers to 90° and 270° upon the position-circle, or, in other words, let the star now run along the line *a a*. Open the parallel lines to any number of revolutions apart, and observe the time occupied by any standard star (if near the pole the better) in passing from line to line. The product, interval in seconds of time × 15 × cosine of star's declination, will be the number of seconds of arc equivalent to the number of re-

volutions by which the lines are separated*. The value of the scale once well determined may be used on every occasion afterwards with the same telescope

We may now direct the telescope to a double star, and proceed as follows

Method of observation

By means of the rack and pinion, turn the position line till the two stars are bisected by it, and the vernier will then show the required angle of position Next, move the parallel lines *b b* and *c c* till each of them bisects one of the stars The revolutions and parts taken from the scales and converted into arc will give the distance sought

The usual and proper method of proceeding is to leave one of the lines fixed at zero, and, by moving the instrument, or by turning one of the screws of the Slipping Piece †, if the instrument be furnished with one, to make this line bisect each star alternately The bisection of the second star is made with the other line, and the reading of its micrometer head recorded Each pair of readings will obviously give the distance between the objects, free from index error, inasmuch as the distance between the first and second position of the micrometer line is equal to twice the distance between the objects

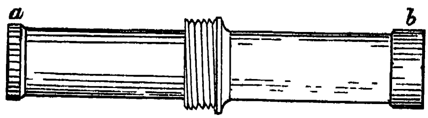
* Although the result of the method above described will be the most accurate, the value of the scale may nevertheless be determined by referring it to the divisions upon the declination circle Having set the vernier of the position circle to zero, open the parallel lines any number of revolutions, say twenty Move the instrument upon the declination axis until one of them bisects a star, and in this position read the verniers of the declination circle Then by means of the tangent screw move the instrument until the other line bisects the same star, and again read the verniers The difference of these readings will be the minutes and seconds of arc equivalent to twenty revolutions of the micrometer-screw

† This is simply a box containing a frame, to which two motions at right angles to each other may be given by means of delicate screws, the box adapting to the end of the telescope and the micrometer to the moveable frame It is useful when a clock is employed to give motion to the instrument, for it enables the observer not only to correct for any small inequality or error in the rate of the clock itself, but likewise to make the lines bisect any object without disturbing their relative position or interfering with the apparatus connected with the clock

It hardly need be suggested that at least five measures of position and as many of distance should be obtained, and a mean of them taken It is not however necessary that the bisection with the fixed line should be of each star alternately, the same star may be bisected by it any number of times successively, but then, throughout an equal number of succeeding observations, it should be made to bisect the second star

The negative Achromatic or Barlow lens * is frequently supplied with the Parallel Line Position Micrometer It is introduced between the eye-piece and the object-glass, and has the property of increasing the magnifying power irrespective of the eye-piece, by which means the increasing of the apparent thickness of the lines with such increase of power is avoided An adapting tube (fig 47), having a screw near the middle of its length, fixes into the eye-tube of the

Fig 47



telescope The Barlow lens is at *a*, and the micrometer, or other eye-piece, at *b*

Double-image Micrometer

The double-image Micrometer is, in principle, similar to the Dynameter described at page 23 It consists of an eye-piece having four lenses, of which the second (from the object-glass) is bisected, and has one of its segments moveable by a micrometer-screw The entire revolutions of this screw are shown upon an exterior scale, and the fractional parts upon the micrometer head The scales should each read 0 when the eye-piece shows but one image The first, or exterior scale, is adjusted by the maker, and the scale of the micrometer head in this case, as in the one just treated of, turns round upon the screw for the purpose of adjustment to zero. The magnifying power is varied by a change of the

* Philosophical Transactions, 1834

lens next the object-glass, for which purpose four lenses are usually supplied

There are two first eye-pipes, in all respects similar to one another, excepting that in one of them a single wire is stretched across the middle of the field of view, which wire is essential for the adjustment of the position-circle as well as for obtaining the value of the revolutions on the micrometer-screw. The other eye-pipe is used for making the observations

A frame, adjustable by means of a screw, is placed between the eye-piece and the position-circle, its object being to give to the images formed by the two segments an equal degree of brilliancy

The position-circle resembles that of the parallel line micrometer, indeed it is common to have a single circle to which one or other of these instruments may be applied at pleasure

To adjust the zero of the position-circle

Direct the telescope to a star, separate the images, and turn the eye-pipe till they are bisected by the wire This step places the wire in a line with the centres of the semi-lenses Finally, set the verniers to 360° and 180° upon the position-circle, and, retaining them there, turn the entire micrometer within the eye-tube of the telescope, till the star continues bisected by the wire when the telescope is moved upon the declination axis This adjustment is then complete

To obtain the value of the micrometer-screw.

Set the verniers to 90° and 270° upon the position-circle, separate the images any number of revolutions, say 10, and, having clamped the hour-circle, note the interval of time between the passages of the two images of the star across the wire The interval × 15 × cosine of star's declination will give the value sought

The above preparation having been carefully made, the position and distance of a double star may be thus determined

1st For Position —Separate the images, and, by turning

the index-plate of the position-circle by means of the rack and pinion motion, place the four stars in a straight line. The verniers will then show the angle of position.

2nd. For Distance.—Let the stars be designated *a* and *b*. Place *a* upon *b*, and *b* upon *a* alternately, and the mean of the readings will give the distance free from index error.

For double stars of very nearly equal magnitudes, or for such as are too minute to bear an illuminated field, this instrument is well adapted.*

* For further information on this subject, refer to papers by the Astronomer Royal in vol. xv. of the Memoirs of the Royal Astronomical Society, and in the Introduction to the Greenwich Observations for 1848, and for information respecting the Object-glass, Annular, and other Micrometers, see Dr. Pearson's Introduction to Practical Astronomy.

THE OBSERVATORY

In so variable a climate as that of England, where opportunities for astronomical pursuits, especially at some seasons of the year, are rare, and even those generally of short duration, it is hardly possible to persevere in anything like a systematic course of observations, unless the instruments are protected by some sort of covering in the shape of an observatory, however humble and unpretending it may be The amateur, who has no object beyond the gratification arising from a telescopic view of the heavenly bodies, has merely, in favourable weather, to carry out his telescope and proceed at once to his amusement, and even to one who ascends a step higher, and indulges in the luxury of an equatorial stand—a stone slab upon a lawn with three grooves to guide the feet of his instrument to their proper position—or a similar guide in an open balcony, or upon the flat roof of a house, is all that is absolutely required to render such means available at very few minutes' notice. But to one who desires to join in the race of astronomical discovery, or can find pleasure only in that degree of exactness of which astronomical observations are capable, something more is needed than the mere extemporaneous equipments above adverted to.

It is quite possible, indeed, and not an uncommon practice, to leave the stand of a Transit Instrument in the open air, or protected only by some water-proof covering, and to carry out the instrument and rectify it for an evening's observations by means of the level and meridian mark, and so also with respect to an Equatorial But in nine cases out of ten the evening which promised to be fine turns out cloudy and unfavourable, and nothing in such a case remains for the astronomer, after all the labour of carrying out and adjusting his instruments, but to remove them from their stands and

replace them in their boxes A few such disappointments, with the fruitless exposure to night air, and perhaps some unpleasant inroad upon the health, have a wonderful effect in chilling the ardour, even of one who commences with good preparation and with no common degree of zeal

But the erection of an observatory is an undertaking from which many recoil who spend liberally in the purchase of good and efficient instruments Such a work is associated in the imagination with much costly machinery and some architectural decoration, all which, where economy is not an object, may be desirable things enough, in so far as they add to the comfort, or display the taste of the proprietor—but that they are not indispensable, the author believes he can show by citing one or two examples

The late Edward Troughton, who resided constantly in London, and in one of its most crowded thoroughfares, contrived a support for an instrument by fixing two beams of fir, parallel to each other and about 12 inches apart, into the opposite side, or party-walls of his house The walls were about 15 feet asunder, and the beams extended from side to side perfectly untouched by the roof or other part of the building The beams were tied together by blocks of wood between them in two or three places, and a stone slab about 4 inches thick was laid upon them, and upon this the instrument was fixed

The standing room was upon a flooring, suspended by iron rods from the rafters above, and two steps on each side enabled the observer to pass from the north to the south side of the flooring, or the reverse, without risk of touching the beams or otherwise disturbing the instrument.

The observatory was in the first instance covered by a revolving dome of copper, which continued there many years—but on falling into bad repair was replaced by a door sliding sideways upon the roof of the house

The front of the house, having very nearly a southern aspect, and being as lofty as the buildings around it, gave a clear and uninterrupted view of the meridian from the north-

ern to the southern horizon, or very nearly so, and a chink in the masonry of St Andrew's Church in Holborn, at about the third of a mile distance, being exactly to the north of the observatory, served excellently as a meridian mark

To the east and west, at about two hours from the meridian, the view was intercepted by chimneys, so that, although the place was admirably adapted for meridional observations, it was limited in its range for an Equatorial or an Altitude and Azimuth Instrument

In this humble erection, through a long course of years, beginning at about the year 1780—several instruments which subsequently became known in the annals of practical astronomy were completed and verified—many hints suggestive of important improvements were obtained, and by the experience of their working and of the wants of astronomy in this department, aided by his great natural taste and talent, the distinguished proprietor was led to the adoption of that symmetry of form, and unprecedented accuracy in all the details of astronomical instruments, for which his works are so deservedly celebrated

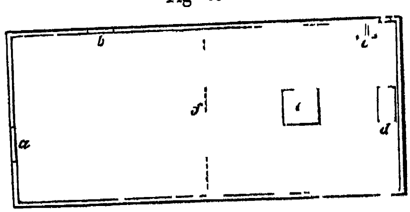
It may excite wonder, that in such a situation as Fleet Street, any such thing as an astronomical observation could be made at all, seeing that the place is in an almost perpetual state of trembling and vibration, a condition which contrasts amusingly with the pains that are taken to ensure steadiness, even in places remote from towns, and to all appearance free from every immediate cause of disturbance But Troughton's method was to take the time, or the declination, as the case might be, when the object vibrated equally on both sides of the diaphragm-wire of the instrument, and he jocularly insisted that such a condition was preferable to perfect steadiness — and although the author cannot subscribe to this view of the case, he can attest without hesitation that the accuracy of which observations, whether of right ascension or of declination, are in such a place susceptible, is truly surprising, and with a disciplined eye not greatly inferior to others made under no such disadvantage

One fact in connection with this observatory may be mentioned as indicative of the extent to which vibrations are propagated by means which appear quite inadequate for the production of such effects Of the twenty-four hours of each day, two only in Fleet Street are hours of comparative repose, and those are between two and four in the morning, for about the former hour the last loiterer in our places of amusement is on his way home, and at the latter the laden waggons of the market gardener are again rumbling along the street During this interval only an occasional carriage passes, and its approach can be seen by the apparent vibrations of a star in the field of the telescope, some considerable time before the faintest murmur of the rolling of the wheels upon the pavement is detected by the ear.

The modern representative of Troughton's Observatory stands within a few yards of its predecessor, and was designed for a Clock, a Transit Instrument, and an ordinary Equatorial of the zodiacal form It has however been superseded by one at the distance of a few miles from London, to which the instruments have been removed, and of which the following is a description

Fig 48 is a plan of the building The length of it is

Fig 48



16 feet, the breadth 7 feet, and the height 7 feet The length is fixed due east and west The door is situated at *a*, a window at *b*, the support of the clock at *c*, the pier for the Transit Instrument at *d*, and a similar one at *e* for the Equatorial To the south of the Transit Instrument is a narrow opening closed by a door it descends below the horizon of the instrument, which can by this means be directed to a meridian

mark Between the flooring and the piers a considerable space is left in order to prevent the possibility of contact, this must in all cases be carefully attended to, or vibrations will be communicated to the instruments, and perhaps even their adjustments disturbed The sides and ends of the building are formed of an open but well-braced framework of timber, the outside being covered with asphalt felt well-coated with paint, and the inside with an oak pattern paper strained upon canvas, which gives to the room a neat and finished appearance

The roof is flat and nearly level, only sufficient inclination being given to it to drain off rain upon one side Half the room from *a* to *f* is permanently closed, and gives space for a chair and table The other half, or that part in which the instruments are placed, is covered by a shutter which can be run off upon the covered part For this purpose an iron rail the length of the building is screwed down on each side, and upon the under side of the shutter several rollers are fixed which run upon the rails The top, like the sides, is covered with asphalt felt

The piers for the instruments are of brick, built in Roman cement, and the pier for the clock is formed of two deals $1\frac{1}{2}$ inch thick and about 10 feet long, screwed together in planes at right angles to one another ($\perp$ is the horizontal section), fixed erect in the ground, 4 feet of the length being beneath the surface

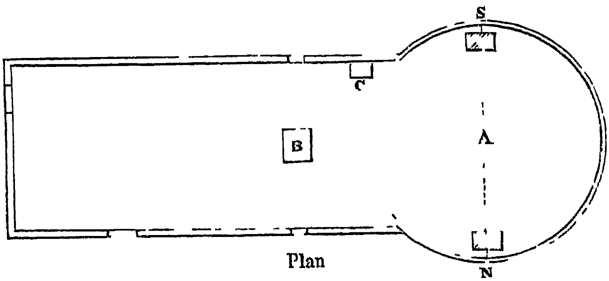
When the Transit Instrument alone is in use it suffices to remove the shutter a few inches, but when observations are to be made with the Equatorial, it is rolled away until the space *d f* is entirely uncovered, thus giving a clear and uninterrupted view of the heavens

This kind of roof is suited only to the Fraunhofer and zodiacal forms of Equatorial, which admit of the telescope being placed just beneath the shutter, a condition essential, inasmuch as the view for several degrees above the horizon would otherwise be obstructed by the sides of the building

The small cost of such a covering for an Equatorial is not

its only recommendation a telescope performs better in the open air than when directed through any aperture or window whatever, it being impossible in such a case altogether to avoid eddies of differently heated currents of air, which are invariably fruitful sources of mischief, and frequently destructive of everything like satisfactory vision It is further to be observed, too, that to a beginner in astronomy a knowledge of the visible heavens is neither a useless nor an unpleasing attainment, and this is not to be made by an observer who looks at the stars through an opening in the roof of an observing room, unless he make it a distinct object of study

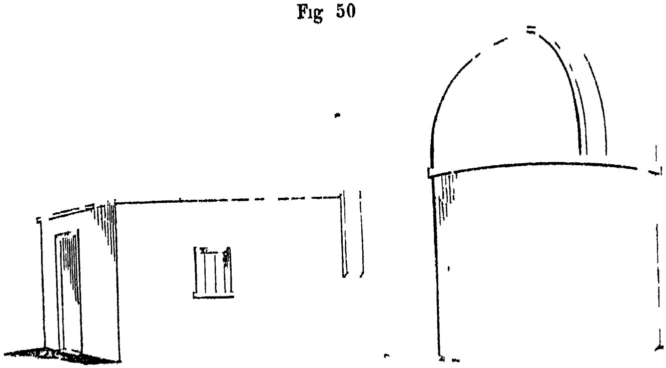
Fig 49



Plan

The form of observatory pretty generally adopted is shown in plan and elevation by figs 49 and 50 The circular room

Fig 50



Elevation

A is intended to receive the Equatorial, and is surmounted by a revolving roof, to which either a cylindrical or a conical form is often given, as being less expensive, though certainly less elegant, than the hemispherical

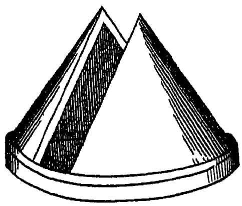
If the instrument be of the Sisson form, two piers will be required for its support, but if it be after the pattern of Fraunhofer, one only, in the centre of the room, will be needed The Transit Instrument may be fixed at B, and the clock at C, where it can be seen by an observer at either instrument The opening for the Transit Instrument is carried across the roof and down the opposite walls of the building, in order that the telescope may command the entire meridian, which should cross the building at right angles, or nearly so The shutter over the opening across the roof should either slide off laterally, or be altogether removeable In all cases it seems desirable that observatory shutters should not, when open, stand perpendicularly upon the roof, for should the wind blow against them, not only is there produced a draft extremely inconvenient to the observer, but a stir and agitation are kept up before the object-glass by no means favourable to its performance A further and serious objection to erect shutters upon revolving roofs is this —in some positions of the telescope upon a Sisson's or a Fraunhofer's Equatorial, such a shutter obstructs the view, and in effect greatly contracts the aperture

It is a too common fault to make the openings in roofs narrower than they ought to be Eighteen inches is not too wide in any case, and in domes of very large diameter the opening should be much wider in fact, as before stated, the more nearly an approach can be made to the condition of the open air, the better, in a general way, will the telescope perform

With regard to the most eligible form for a revolving roof, nothing can be said absolutely. The cylindrical, if appearance be but a secondary object, is so easily constructed, and affords such ready means for adapting close and effective shutters, that its adoption may be safely recommended. A roof having

a conical form, constructed by the Rev Samuel King, and now the property of Warren De la Rue, Esq, is, perhaps, as appropriate and inexpensive a thing of the kind as can be met with It is represented by fig 51

Fig 51



The interior diameter of the base is 8 feet 6 inches, and the perpendicular height 4 feet 3 inches The framework is of deal, in all respects as light as is consistent with a due regard to strength, and the external covering is canvas, made impervious to moisture by a strong coat of paint The width of the opening is 18 inches, and extends on both sides from the apex to the base The shutters are of deal, and are removed by lifting off from the outside, an operation easily performed by a person of ordinary height standing on an elevation of about 2 feet above the surrounding lawn One end of each shutter rests upon the base of the cone, and the sides project sufficiently beyond the opening to prevent the intrusion of rain or snow The shutter, which generally remains in its place, has upon its upper end a projecting lip which perfectly closes the apex, and each shutter is held securely in its place by a cross bar, or button, which turns upon a centre, and enters a mortice on each side of the opening

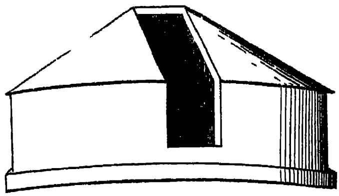
Upon the under side of the base are fixed eight rollers of 3 inches diameter, which run upon an iron ring screwed down upon the wall-plate Eight similar rollers act against the curb of the dome, and retain it in a central position Very little force is required to put it into motion, and its action is most effective and satisfactory

The roof just described was made to cover an Equatorial

of the kind shown by fig 38, carrying a telescope of 5 feet focal length and 4 inches aperture Such an apparatus is so manageable, and in every respect so well-adapted to the purposes of the amateur, that few will be tempted to exceed these moderate dimensions

Another form of revolving roof, fig 52, combines the cy-

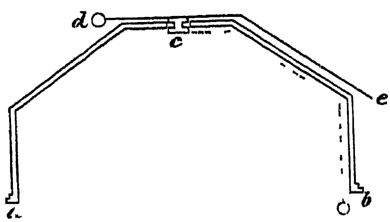
Fig 52



linder and cone, and has an opening extending from the apex down to the base, or very nearly so The shutter for the cylindrical part opens inwards, whilst, as regards that upon the cone, it may be made to remove entirely, or if this be objected to, or the outside of the building be not easily accessible, the following method may be adopted

Let *a*, *c*, *b* (fig 53) represent the roof in section At *c*, in the centre, an axis with flanges above and below turns within

Fig 53



a socket formed of two parts or *half holes* To the upper flange the shutter *d e* is firmly screwed, *d* being one of two counterpoises, so placed, as, when the shutter is open, to be perfectly clear of the opening To the lower flange at *c* an arm is attached, which, passing round to *b* in the direction

of the dotted line, is within reach of the hand of a person standing on the floor of the observatory

That this construction of shutter does not admit of the opening being extended beyond the apex, is no objection to its adoption if the Equatorial be of the Sisson or the Fraunhofer form, for the eccentricity of the telescope on either of those instruments requires that the opening be turned in the direction of the Prime Vertical in order to make a zenithal observation The necessity for doing so, might, indeed, be avoided by making the width of the opening at least equal to twice the eccentricity of the telescope, but this, in most cases, would exceed all reasonable dimensions, and with so simple a remedy at hand deserves no consideration whatever

The form of shutter last described is likewise applicable to a hemispherical dome, but the most suitable, perhaps, is that which extends through a quadrant, and runs upon rollers on parallel ridges outside The ridges are continued from horizon to horizon, but the opening is on one side only, viz from the horizon to the zenith, or nearly so Fig 54 is a cross section of the dome and shutter Fig 55 shows a section at right angles to the last, and exhibits the apparatus for opening and closing the shutter The two extremities of a cord of suitable length are tied to the end of the shutter at *b*. This cord passes over a series of pulleys without and within the dome in the direction of the dots, and at *c*, a weight, which nearly counterbalances the shutter, is secured to it The figure shows the shutter open, the effect of the weight at *c* being to assist in causing it to revolve on the outside of the dome towards *f*, and so to close the aperture *a f* When, by a gentle pressure, the weight is brought to *d*, the middle of the shutter is over the apex of the dome, and, when the shutter is closed, *i e* occupies the position *a f*, the weight will be at *c'*, from which it will again descend towards *d* when the shutter is reopened A bracket might depend from the base of the dome, and receiving the weight before it descend to the point *d*, retain it till the descending shutter again bring it into action

Fig 54

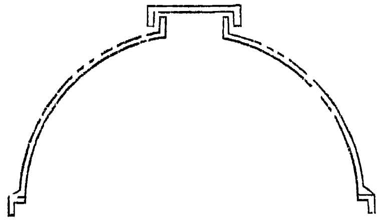
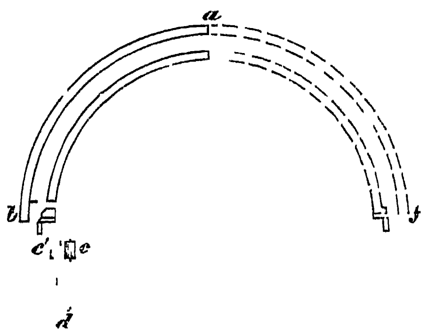


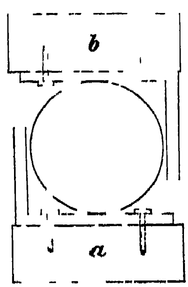
Fig 55



It is desirable to have a small window in some convenient part of a dome in order that sufficient light may be admitted for the observer's occasional occupation about the instrument

The rotation of a dome is most easily effected upon three spheres, or cannon-balls, arranged at equal distances beneath the base The channel in which they run may consist of two

Fig 56



rings of iron, the cross section of which is in the form of the letter **L**, as represented by fig 56, in which *a* represents the

circular wall-plate of timber, and *b* the base or curb of the dome. Care must be taken that the wall-plate is perfectly horizontal, and that the balls are of exactly the same diameter. The consequence of inattention to these particulars will be that the balls will change their positions with respect to each other, and must be replaced before the dome will rotate with facility.

A dome of 8 or 10 feet diameter, if the channel be well-laid, and there be no temporary obstruction, can be moved by hand without exertion to an inconvenient degree; but, for giving motion to larger domes, recourse must be had to suitable mechanical aids, the particulars and mode of application of which are described in many treatises on practical mechanics.

I shall conclude by referring the reader for examples of existing Observatories, and other information of great value, to the following works, viz.—

Memoirs of the Royal Astronomical Society.

Dr. Pearson's Introduction to Practical Astronomy.

A description of the Northumberland Equatorial and Observatory erected at Cambridge, by G. B. Airy, Esq., Astronomer Royal.

Results of Astronomical Observations made at the Cape of Good Hope, by Sir J. F. W. Herschel, Bart., in which is given a description and figures of a revolving roof of a pyramidal form.

The article on Observatories in "LONDON and its Vicinity exhibited in 1852." John Weale, High Holborn.

A Cycle of Celestial Objects, by Capt. W. H. Smyth, R.N.

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Ditto, Hand Frames	from 7*s* 6*d* to	0	16	0
Fine Blue Steel Spectacles, Single Joint		0	10	6
Ditto, Double Joint		0	12	6
Eye Glasses, Gold Frame	from 1*l* 1*s* to	2	2	0
Ditto, Silver Frame	from 6*s* to	0	8	6
Ditto, Shell Frame	from 4*s* 6*d* to	0	6	0
(*If with Brazilian Pebbles, 6s per pair extra*)				
Spectacle Cases	each	0	1	0
Opera Glasses, Achromatic, Ivory Bodies and Gilt Mountings	from 2*l* 2*s* to	5	5	0
Ditto, Double Bodies	from 5*l* 15*s* 6*d* to	10	10	0

TELESCOPES

			£	s	d
1	One-foot Achromatic (Camp) Telescope, having one Drawer		1	5	0
2	Ditto ditto, Portable, with Drawers		1	9	0
3	Ditto ditto, in Electrum		2	2	0
4	Ditto ditto, larger aperture in Brass		1	15	0
5	Ditto ditto, in Brass, with extra Eye-piece and Rest, in a Maroon Case		3	3	0
6.	Eighteen-inch ditto, in Brass		2	12	6
7	Two-feet ditto, Reconnoitring		3	13	6
8	Ditto ditto, in Electrum		5	5	0
9	Ditto ditto, in Electrum, with Compass, &c		6	6	0
10	Ditto ditto ditto, with four Drawers in Brass		4	4	0
11	Thirty-inch ditto	ditto	5	5	0
12	Three-feet ditto	ditto	6	6	0
13	Military Cases and Slings for the above Telescopes,	from 10*s* 6*d* to	0	12	6
14	Portable Brass Stand for the above Telescopes,	from 21*s* to	2	12	6
15	Dumpy Day or Night Glass		4	4	0

No.	Item	£	s.	d.
16	Dumpy Day or Night Glass, with Pancratic Eye-piece	4	11	6
17	Two-feet Navy Telescope	2	12	6
18	Ditto ditto, Brass Body, covered with Leather	2	15	0
19	Ditto ditto, with Spray Shade	3	3	0
20	Three-feet ditto, with Spray Shade	5	15	6
21	Four-feet ditto, with Two Powers, in a Case	12	12	0
22	Day or Night Telescope (Deck Glass), with Spray Shade	1	1	0
23	Night Glass	4	1	0
24	Ditto, Achromatic	5	15	6
25	Ordnance Signal Station Telescope	6	16	6
26	Thirty-inch Achromatic Telescope, two-and-a-quarter-inch Object Glass, mounted on Brass Pillar-and-claw Stand, with a Terrestrial and an Astronomical Eye-piece, in a Mahogany Case	10	10	0
27	Ditto, with Vertical Rack Motion	12	12	0
28	Ditto, with two-and-three-quarter-inch Object Glass, with Terrestrial Eye-piece to vary the Magnifying Power, three Astronomical Eye-pieces, and Tubular Stand, which, when drawn out, raises the Telescope to a convenient height for use—the whole packed in one Case about thirty inches long this instrument is powerful both as a Terrestrial and as an Astronomical Telescope, and is applicable to observations of Jupiter's Satellites, Occultations of Stars by the Moon, &c	23	2	0
29	Ditto, but having Finder and Vertical and Horizontal Rack Motions	31	10	0
30	Forty-five-inch Achromatic Telescope, two-and-three-quarter-inch Object Glass, on Brass Pillar-and-claw Stand, with a Terrestrial and an Astronomical Eye-piece, in a Mahogany Case	23	2	0
31	Ditto, but having Finder, Vertical Rack Motion, and an extra Eye-piece	26	5	0
32	Ditto, two-and-three-quarter-inch Object Glass, with Horizontal Rack and Steadying Rods, complete	31	10	0
33	Ditto, with three-and-a-quarter-inch Object Glass, with Rackwork Motions, Finder, one Terrestrial and three Astronomical Eye-pieces, in a Mahogany Case	42	0	0
34	Ditto, but having Steadying Rods, additional	48	0	0
35	Ditto, with three-and-three-quarter-inch Object Glass, mounted as above	68	[illegible]	0
36	Equatorial Stand, instead of Pillar-and-Claw to the above Telescopes, constructed to any given Latitude	extra 30	0	0

		£	s	d
37	Achromatic Telescope, three-and-three-quarter-inch Object Glass, with Finder, Eye-pieces, &c, 5 feet local length, mounted upon a Universal Equatorial Stand	110	0	0
38	Ditto ditto, 4-inch Object Glass	140	0	0
39	Ditto ditto, 4-inch Object Glass, mounted Equatorially on an Iron pillar, with Clock Motion, &c	150	0	0
40	Completely mounted, Equatorial, with Clock Movement, Micrometer, &c, 5 feet focus and 4-inch Object Glass	230	0	0
41	Equatorial Instruments of larger dimensions, having Telescopes varying from four-and-a-half to nine-inch Aperture, with finely graduated Circles, Clock Movement, Micrometers, &c from 300*l* to	800	0	0
42	Universal Equatorial, with Telescope of thirty inches focal length and two-and-three-quarter aperture, with declination Micrometer	84	0	0
43	Ditto, with Telescope of three-and-three-quarter-inches aperture, with declination Micrometer	120	0	0
44	Varley's Stand, Mahogany, with Brass Fittings	12	12	0
45	Ditto ditto, larger size	15	15	0
46	Collimating and Referring Telescopes, Magnetometers, &c for use in Magnetic and other Observatories			

SEXTANTS, QUADRANTS, COMPASSES, ETC

		£	s	d
47	Troughton and Simms's newly-invented double Sextant, for Coast and Harbour Surveys.	14	14	0
48	Metal Sextant, 8-inch Radius, Double Frame, divided on Gold to 10 seconds	23	2	0
49	Ditto ditto, divided to 10 seconds, on Platina	21	0	0
50	Ditto ditto, divided to 10 seconds, on Silver	18	18	0
51	Ditto ditto, Solid Frame, 7-inch, to 10 seconds, on Silver	16	16	0
52	Ditto ditto, 6-inch, to 20 seconds	14	14	0
53	Ditto ditto, 5-inch, to 20 seconds	13	13	0
54	Ditto ditto, 4-inch, to 20 seconds	10	10	0
55	Ditto ditto, 5-inch, to 20 seconds, with Becher Horizon and Steadying Rod, in one Case	22	0	0
56	Ditto ditto, 7-inch, Plain Cast Frame, to 10 seconds	11	11	0
57	Ebony Sextant, with Brass Arch	10	10	0
58	Troughton's Reflecting Circle, 10-inch	23	2	0
59	Ditto ditto, 12-inch	27	6	0
60	Borda's Repeating Circle by Reflexion, 6-inch	21	0	0
61	Ditto, 8-inch	23	2	0

		£	s	d
133	Five-inch Cradle Theodolite	21	0	0
134	Five-inch ditto (best construction), divided on Silver, Tangent-screw Motions, &c	25	4	0
135	Five-inch ditto, with two Telescopes	31	10	0
136	Six-inch ditto, divided to 20 seconds, with one Telescope	31	10	0
137	Six-inch ditto, with two Telescopes	40	0	0
138	Five-inch ditto, with one Telescope, Transit Axis and Vertical Circle	32	10	0
139	Five-inch ditto, with ditto, ditto, and Axis, Level, Lantern, &c	37	10	0
140	Six-inch ditto, with ditto, ditto, and Vertical Circle	36	15	0
141	Six-inch ditto, with ditto, ditto, and Axis, Level, &c	42	0	0
142	Five-inch ditto, with two Telescopes, Transit Axis, &c, Axis, Level	40	10	0
143	Six-inch ditto, with ditto, ditto	50	0	0
144	Seven-inch ditto, with one Telescope	35	14	0
145	Seven-inch ditto, with two Telescopes	45	0	0
146	Seven-inch ditto, with Transit Axis, Vertical Circle, one Telescope, Axis, Level, &c	48	10	0
147	Eight-inch ditto, Azimuth and Altitude, with Axis, Level, &c	52	10	0
148	Ten-inch ditto, ditto	65	0	0
149	Twelve-inch ditto, for Horizontal Angles only	12	0	0
150	Everest Theodolite, 4-inch	22	0	0
151	Ditto, ditto, 5-inch	26	5	0
152	Ditto, ditto, 7-inch	36	15	0
153	Kater's Circle, five-and-a-half-inch, complete	35	0	0
154	Ditto, 3-inch	16	0	0
155	Kater's Floating Collimator, six-and-a-half-inches	8	8	0
156	Level Collimators from 10*l* 10*s* to	15	15	0

(*Larger Theodolites, &c made to Order.*)

STATION POINTERS, PROTRACTORS, PENTAGRAPHS, ETC.

		£	s	d
157	Twelve-inch Station Pointer	6	16	6
158	Eighteen-inch ditto	7	17	6
159	Twenty-four-inch ditto	9	9	0
160	Thirty-inch ditto	12	12	0
161	Three-feet ditto	18	18	0
162	Six-inch best Brass Circular Protractor, with folding Arms and Rack and Pinion	4	14	6
163	Ditto, divided upon Silver	5	15	6

			£	s	d
164	Eight-inch best Brass Circular Protractor, divided upon Brass		7	7	0
165	Ditto, ditto, divided upon Silver		8	8	0
166	Metcalfe's Semicircular Protractor		6	16	6
167	Six-inch Protractor, with Vernier and Arm		3	3	0
168	Eight-inch ditto, ditto		3	13	6
169	Fifteen-inch plain Circular Protractor		3	5	0
170	Ten-inch ditto		3	0	0
171	Eight-inch ditto		1	11	6
172	Six-inch ditto		1	1	0
173	Semicircular plain Protractors	from 16*s* to	2	2	0
174	Ivory Protractors	from 6*s* to	0	18	0
175	Ditto, upon Parallel Rollers	from 18*s* to	1	5	0
176	Ditto ditto (Chaplin's)		1	11	6
177	Eighteen-inch best Brass Pentagraph		5	5	0
178	Twenty-four inch ditto		6	6	0
179	Thirty-inch ditto		7	7	0
180	Three-feet ditto		8	8	0
181	Three-and-a-half-feet ditto		9	9	0
182	Four-feet ditto		11	11	0
183	Plain Perambulators (Wood)		9	9	0
184	Ditto, Brass-mounted		11	11	0
185	Best ditto, with Metallic Wheel		15	15	0
186	Trochiameter, for counting the Revolutions of a Carriage-wheel		2	5	0
187	Leather Case and Strap for ditto		0	10	6
188	Common twelve-feet Levelling Staff		1	11	6
189	Best ditto		1	15	0
190	Troughton's Portable ditto, with Level		2	12	6
191	Sopwith's ditto, 14-feet		2	12	6
192	Ditto, 16-feet		3	13	6
193	Ditto, Painted	from 3*l* 3*s* to	4	4	0
194	Gravatt's Levelling Staff, 17 feet		3	13	6
195	Ditto, Painted		4	4	0

TAPE MEASURES, CHAINS, ETC

		£	s	d
196	Tape Measure, 25 feet, links	0	7	0
197	Ditto, ditto, decimals	0	8	0
198	Ditto, 33 feet, links	0	8	0
199	Ditto, ditto, decimals	0	9	0
200	Ditto, 50 feet, links	0	10	0

			£	s	d
201	Tape Measure, 50 feet, decimals		0	12	0
202	Ditto, 66 feet, links		0	12	0
203	Ditto, ditto, decimals		0	11	0
204	Ditto, 100 feet, links		0	16	0
205	Ditto, ditto, decimals		0	18	0
206	Land Chain, 50 feet, and Arrows		0	13	6
207	Ditto, 100 feet, and ditto		1	5	0
208	Ditto, 66 feet, with three Oval Rings, &c		1	1	0
209	Standard Chain, 50 feet	4l 4s. to	5	5	0
210	Ditto, 66 feet	5l 5s to	6	16	6
211	Ditto, 100 feet	8l 8s to	9	19	6

(Stronger Chains, &c made to Order.)

DRAWING INSTRUMENTS, SCALES, RULES, ETC

			£	s	d
212	Camera Lucida	from 1l 11s. 6d to	2	12	6
213	Stand for ditto	from 1l 1s to	1	11	6
214	Drawing Instruments, in Skin Cases (Sappers and Miners)		0	14	0
215	Ditto, ditto, East India Company's pattern		1	5	0
216	Ditto, ditto, Mahogany Case, Addiscombe pattern		3	8	0
217	Ditto, ditto, Sector-jointed Instruments, Parallel Rulers, Sector and Protractor		3	13	6
218	Ditto, ditto, with Sector double-jointed Dividers		4	4	0
219	Ditto, ditto, with proportional Compasses		5	15	6
220	Ditto, ditto, with Spring Bows		7	7	0
221	Ditto, ditto, with Road and Wheel Pens, Needle-holder, small Dividers, &c		9	9	0
222	Ditto, ditto, in Electrum, packed in Rosewood and Mahogany Cases, best description	from 5l 5s to	13	13	0
223	Ditto, ditto, large Magazine Cases	from 26l 5s to	35	0	0

(Cases of Instruments fitted up to order.)

			£	s	d
224	Proportional Compasses, Brass, 6-inch, plain		1	11	6
225	Ditto, ditto, with Adjusting Screw		2	2	0
226	Ditto, ditto, Electrum, 6-inch, plain		2	2	0
227	Ditto, ditto, with Adjusting Screw, Electrum		2	12	6
228	Plain Beam Compasses		1	15	0
229	Beam Compasses with Double Adjustments and Divided Beam	from 4l 4s to	6	6	0
230	Ditto, ditto, Tubular Beam	from 5l 5s to	10	10	0
231	Marquois Scales, in Boxwood	from 12s 6d to	0	16	0
232	Ditto, in Ivory		2	15	0
233	Ditto, in Brass		3	4	0

			£	s	d
234	Marquois Scales, in Electrum		4	4	0
235	Twelve-inch Ivory Plotting Scales	from 11*s* to	1	1	0
236	Ditto, Boxwood, ditto	from 4*s* to	0	7	6
237	Ivory Offset and Pocket Scales	from 2*s* 6*d* to	0	7	0
238	Gunter's Scale, Brass, 2 feet		2	2	0
239	Ditto, Boxwood	from 5*s* to	0	9	0
240	Ivory folding Rules	from 10*s* to	0	18	0
241	Boxwood, ditto	from 6*s* to	0	15	0
242	Gunner's Rules	from 3*s* to	0	10	6
243	Engineer's Rules of various kinds				
244	Plain Ebony Parallel Rulers	from 1*s* 6*d* to	1	10	0
245	Ditto, ditto, with Brass Edges	from 10*s* 6*d* to	2	12	6
246	Plain Rolling Ebony Parallel Rulers, per inch		0	1	0
247	Ivory Edged and Graduated ditto, per inch		0	1	6
248	Brass Edged, plain ditto, per inch, plain		0	1	6
249	Brass Edged and Graduated ditto, per inch		0	2	0
250	Parallel Rulers made in Electrum, &c, Curves (in Wood), Concave, Convex, &c, Brass Scales, and Brass and Steel Straight Edges of various lengths				
251	Brunel's, Napier, Pillar Compasses, &c				

HORIZONTAL DIALS MADE TO ANY LATITUDE

		£	s	d
252	Six-inch to 5 minutes	1	1	0
253	Nine-inch to ditto	2	5	0
254	Twelve-inch to 2 minutes, and Equation Table	6	16	6
255	Twelve-inch to ditto, with Turned Edge, &c	7	7	0
256	Fifteen-inch to 1 minute, without Turned Edge	7	17	6
257	Eighteen-inch to ditto, 32 Points Lettered, Equation Table, &c	18	18	0

(*Larger to Order*)

UNIVERSAL JOINT DIALS

		£	s	d
258	Two-and-a-half-inch, in Case complete	2	2	0
259	Three-and-a-half-inch, ditto	2	12	6
260	Four-and-a-half-inch, ditto, with Levels in Compass	4	14	6
261	Six-inch Ring Dial	2	12	6
262	Four-inch ditto	1	15	0

TRANSITS, CIRCLES, ETC

		£	s	d
263	Twenty-inch Transit Instrument, with Iron Stand	21	0	0
264	Ditto, ditto, with graduated Scale to Level, &c	23	2	0
265	Two-feet ditto, with Portable Brass Stand	26	5	0

		£	s	d
266	Two-and-a-half feet Transit Instrument, with Iron Stand	42	0	0
267	Ditto ditto, Improved, two-and-a-quarter aperture .	47	5	0
268	Ditto ditto, two-and-three-quarter aperture	65	0	0
269	Three-and-a-half feet ditto, constructed for fixing upon Stone Piers, complete	84	0	0
270	Ditto, complete, with Two Setting Circles, &c	105	0	0
271	Variation Transit	63	0	0
272	Transit Circle, 18-inches complete, for fixing on Stone Piers	130	0	0
273	Ditto, 2 feet, ditto	220	0	0
274	Ditto, 3 feet, ditto	350	0	0
275	Ditto, 4 feet, ditto	500	0	0
276	Twelve-inch Altitude and Azimuth Instrument, divided on Silver, the Azimuth Circle Reading by Verniers, and the Altitude by Micrometers	105	0	0
277	Fifteen-inch ditto, both Circles reading by Micrometers	130	0	0
278	Ditto, the Altitude Circle 18, and Azimuth Circle 15 inches, with Micrometers	150	0	0
279	Ditto, both Circles 18 inches .	210	0	0
280	Collimator in Axis to either of the above four Instruments, extra	5	5	0
281	Twelve-inch Repeating Circle (Borda's)	81	0	0
282	Eighteen-inch ditto, ditto .	105	0	0

(*Mural Circles, &c to Order*)

		£	s	d
283	Dipping-Needle, best construction .	30	0	0
284	Annular Micrometer, with Eye-piece	1	5	0
285	Parallel Wire Position Micrometer *8l* 8s, *12l* 12s and	15	15	0
286	Double Image Micrometer, with Position Circle, &c .	16	16	0
287	Ditto, ditto, without Position Circle	12	12	0
288	Slipping piece, for use with Position Micrometer	2	12	6
289	Double Image Dynameter	4	11	6
290	Divided Scale Dynameter	1	5	0
291	Reticulated Glass Eye-piece Micrometer, 200 to inch	1	6	0
292	Wollaston's Goniometer .	3	13	6

MICROSCOPES, ETC

		£	s	d
293	Solar Microscopes from *6l* 16s *6d* to	21	0	0
294	Botanic ditto, small size	0	18	0
295	Ditto ditto	1	5	0
296	Compound ditto from *2l* 12s *6d* to	5	15	6
297	Ditto ditto, full size, with Huygenian Eye-piece and two Compound Achromatic Object Glasses, one of two			

		£	s	d
	inches and the other of half an inch focal length, Rack and Pinion Motion and Fine Motion to Object End, Reflector, Camera Lucida, Micrometer Scale into hundredths and thousandths of inches, Pressure Box, Forceps, Condenser, Bottle of Canada Balsam, 6 Slides furnished with Objects, and 24 spare Glass Slides with thin glass to cover Objects, &c, in Mahogany Case	17	17	0
298	Compound Botanic Microscopes, with Lever Stage, three Achromatic Object Glasses—namely, two inches, one inch, and four-tenths of inch focus respectively, with Lieberkuhn for the highest power, Two Eye-pieces, Polarizing Apparatus, &c &c, in Mahogany Case	24	0	0
299	Ditto ditto, very superior, with most improved Stage, four Achromatic Object Glasses—namely, two inches, one inch, half inch, and quarter inch focus respectively, with Lieberkuhn's, Three negative Eye-pieces, large Condenser, Polarizing Apparatus, Camera Lucida, Stage and Eye-piece Micrometers, three Dark Wells and Stage, Nachet's Prism, Condenser and Side Reflector for principal Stage, Apparatus with Side Adjustment and Rack Motion for adapting Achromatic Condenser, &c &c &c, in a Mahogany Case	45	0	0
300	Smaller Achromatic Microscopes from 7*l* 7*s* to	12	12	0

BAROMETERS, THERMOMETERS, ETC

		£	s	d
301	Troughton's Mountain Barometer, best construction	12	12	0
302	Ditto ditto, Gay-Lussac's . .	7	17	6
303	Ditto ditto, Ordnance pattern .	7	17	6
304	Ditto ditto, Englefield's .	5	15	6
305	Ditto ditto, ditto, with Iron Cistern .	7	17	6
306	Leather Cases for Englefield's Barometers each	1	1	0
307	Standard Syphon Barometer .	16	16	0
308	Ditto ditto, with Glass Cover	20	0	0
309	Marine Barometers . from 4*l* 4*s* to	7	17	6
310.	Chamber ditto from 2*l* 2*s* to	13	13	0
311	Best ditto ditto, with Float Gauge	7	7	0
312	Wheel Barometers . from 4*l* 4*s* to	7	7	0
313	Sympiesometer .	4	4	0
314	Tropical Tempest Sympiesometer .	5	5	0
315	Wollaston's Thermometer, with Boiling Apparatus, &c	4	4	0
316	Thermometers from 2*s* 6*d* to	1	15	0

No.	Article		£	s.	d.
317	Standard Thermometers	2*l* 12*s* 6*d* and	3	3	0
318	Six's Self-Registering Thermometers	from 1*l* 1*s* to	2	2	0
319	Horizontal ditto (Maximum and Minimum)	from 15*s* to	1	11	6
320	Day or Night ditto, Singly	from 7*s* 6*d* to	0	13	0
321	Hygrometer, Pocket, Brass		0	12	0
322	Ditto ditto, Gilt		0	18	0
323	Ditto (Mason's), Wet and Dry Bulb		0	18	0
324	Ditto ditto, in Case, for Travellers		1	5	0
325	Ditto, Daniell's		2	12	6
326	Ditto, ditto, Larger Size		4	1	0
327	Rain-Gauge, Funnel, Bottle, &c		0	16	0
328	Ditto ditto, with Scale		2	2	0
329	Ditto ditto, Best		4	4	0
330	Whewell's Anemometer	from 12*l* 12*s* to	15	15	0
331	Lind's Wind-Gauge		3	3	0
332	Geothermometer		2	2	0

(*Various other kinds made to Order*)

AIR-PUMPS, ETC., AND APPARATUS.

No.	Article		£	s.	d.
333	Professor Leslie's Machine for making Ice		78	0	0
334	Ditto for ditto, with one Plate		18	0	0
335	Large Air-Pump, on a Stand, with Barometer Gauge		22	0	0
336	Large Table ditto, with Syphon Gauge		15	15	0
337	Middle Size ditto, with ditto		9	9	0
338	Small Size ditto, with ditto		6	16	6
339	Single Barrel ditto	from 1*l* 11*s* 6*d* to	4	1	0
340	Guinea and Feather Experiment, Receiver included		2	15	0
341	Set of Windmills	from 1*l* 15*s* to	2	12	6
342	Apparatus for Freezing Water		1	1	0
343	A Bell for proving that without Air there is no Sound	from 10*s* 6*d* to	1	11	6
344	Brass Hemispheres, to demonstrate external Pressure	from 20*s* to	1	18	0
345	Model of a Water Pump		1	11	6
346	Double Transferrer		3	3	0
347	Single Transferrer, with Fountain Pipe		1	5	0
348	Glass Vessel for Fountain in Vacuo		0	7	0
349	Six Breaking Squares, Cage and Cap		0	18	0
350	Apparatus for Striking Steel and Flint in Vacuo		0	18	0
351	Copper Bottle, Beam and Stand, for weighing Air		3	3	0

		£	s	d
352	Model of Forcing Pumps for a constant Stream, with glass barrels .	3	3	0
353	Gun Lock Experiment	1	1	0
354	Bacchus ditto	1	14	6
355	Torricellian ditto	0	10	6

(*And various other Experiments*)

ELECTRICAL MACHINES AND APPARATUS, ETC.

		£	s	d
356	A twelve-inch Electrical Plate Machine, packed with Medical Apparatus	7	10	0
357	A fifteen-inch ditto	10	10	0
358	An eighteen-inch ditto .	12	12	0
359	A twenty-four-inch ditto	18	18	0
360	A Cylinder Machine, 16 by 10	12	12	0
361	A ditto ditto, 14 by 8	10	10	0
362	A ditto ditto, 12 by 7 .	7	17	6

(*Larger Machines made to Order*)

		£	s	d
363	Universal Discharger and Press	1	16	0
364	Jointed Discharger, with Glass Handles	0	12	6
365	Ditto, plain from 4s 6*d* to	0	8	6
366	Electrical Batteries of Combined Jars from 2*l* 12s 6*d* to	10	10	0
367	Cuthbertson's Improved Electrometer, with Grain Weight	2	12	6
368	Bennet's Gold-Leaf Electrometer	0	18	0
369	Cavallo's Bottle Electrometer, for Atmospherical purposes, from 12s to	4	14	6
370	Quadrant Electrometer, with divided Arch	0	9	6
371	Kinnersley's Electrometer	1	1	0
372	Coulomb's Electrometer .	1	16	0
373	Pith-Ball ditto .	0	16	0
374.	Luminous Conductors from 12s to	1	0	0
375	Thunder-house, for showing the use of Conductors	0	8	0
376	Thunder-house, with a Drawer	0	9	6
377	Powder House, for showing the use of Conductors	0	16	0
378	An Obelisk or Pyramid for ditto	0	10	6
379	A Magic Picture for giving Shocks from 7s 6*d* to	0	16	6
380	A set of 5 Spiral Tubes on a Stand .	1	16	0
381	A set of 5 Spiral Tubes on a Stand, with a Dome .	2	8	0
382	Luminous Names or Words from 10*s*. 6*d* to	1	11	6
383	A Set of 3 Plain Bells .	0	10	6
384	A Set of 8 Bells, containing the Gamut	1	14	0

			£	s	d
385	Diamond or Spotted Jars	from 8s to	0	16	0
386	A Small Head with Hair		0	8	0
387	Sportsman and Birds		1	16	0

(*All other kinds of Apparatus to Order*)

388	Atwood's Machine for Demonstrating the Law of Acceleration in Falling Bodies	from 20*l* to	30	0	0
389	Working Models of Locomotive Engines	from 20*l* to	40	0	0
390	Model of Bramah's Hydrostatic Press		15	15	0
391	A Small Still with Worm, Tub and Lamp		2	18	0
392	Whirling Table complete		30	0	0
393	Small Balances	from 4*l* 4*s* to	7	17	6
394	Hydrostatic Balance		16	16	0
395	Model of Centrifugal Pump	from 4*l* 10*s* to	7	7	0
396	Bar Magnets for Correcting the Derangement of the Compass in Iron Vessels, 2 feet, each 2*l* 2*s*, 14 inches, each 1*l* 1*s*, 8 inches, each		0	10	6

(*Models of Machinery, &c made to Order*)

BOOKS.

A Treatise on the Principal Mathematical Instruments employed in Surveying, Levelling, and Astronomy, explaining their Construction, Adjustments, and Use, with an Appendix and Tables By Frederick W Simms, Surveyor and Civil Engineer, late of the Royal Observatory, Greenwich, and formerly employed on the Ordnance Survey 7th Edition, enlarged .	0	6	0
A Practical Treatise on Tunnelling By F W Simms . .	1	1	0
Astronomical Tables and Formulæ By the late Francis Baily, Esq, F R S, &c &c. (a few copies only remaining)	0	15	0

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